Studies on soil animals in a remote region of Amazonia : particularly in relation to population assessment using field extractors.

Thesis

UNRESTRICTED

STUDIES ON SOIL ANIMALS IN A REMOTE REGION OF AMAZONIA - PARTICULARLY IN RELATION TO POPULATION ASSESSMENT USING FIELD EXTRACTORS

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A B S T R A C T

This study was undertaken whilst leading expeditions to the Amazon in 1978 and 1981.

Laboratory and field methods of extracting invertebrates in soil are reviewed so as to highlight the problems inherent in collecting soil animals in remote regions. The main problem is to find an efficient, portable extraction unit that will provide reliable population estimates suitable to the environment under study.

Following a detailed analysis of available literature it was decided to test a chemical extraction unit using turpentine as a repellent. This was a modification of Lewis's extraction unit (1970) which was successfully used to repel thrips from flower heads. A trial comparison of the chemical extractor with a dry Tullgren technique using soil samples from temperate oak woodland showed that there was insufficient difference between the results to demonstrate the unsuitability of either technique.

However, when the two techniques were compared with soil samples from tropical rain forest in Amazonia, the dry Tullgren funnel collected more species than the chemical unit. Further, the dry Tullgren funnel results suggested a much higher and more realistic soil animal population estimate than the chemical extractor which in turn was more efficient than a hand-sorting technique.

The literature on tropical soil animal studies is reviewed. A comparative study of the soil animals living in a cultivated field and tropical rain forest soil was undertaken using a chemical extractor. The inefficiency of this type of extractor renders the results inconclusive. The evidence does however suggest that the efficiency of the chemical extractor improved when repelling animals from the

drier soil collected at the cultivated field.

Though the Tullgren funnel was more efficient in isolating organisms and the number of species was greater, the chemical extraction unit was a simpler method and still produced a number of different species so could be a useful and more easily managed tool for taxonomic investigations in remote areas.

A limited number of soil cores collected two days after burning a cleared rain forest site demonstrated that the site still contained soil animals albeit in greatly reduced numbers.

A modification of a type of corer used by Fletcher (1976) is described. This proved to be easily portable yet robust.

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PROLOGUE

In 1975 I was asked to lead the Wallace Expedition to Amazonia (1978) and feeling it would be a pity to waste this opportunity I decided to register for a higher degree with the Open University and to use data collected on this expedition as part of my thesis.

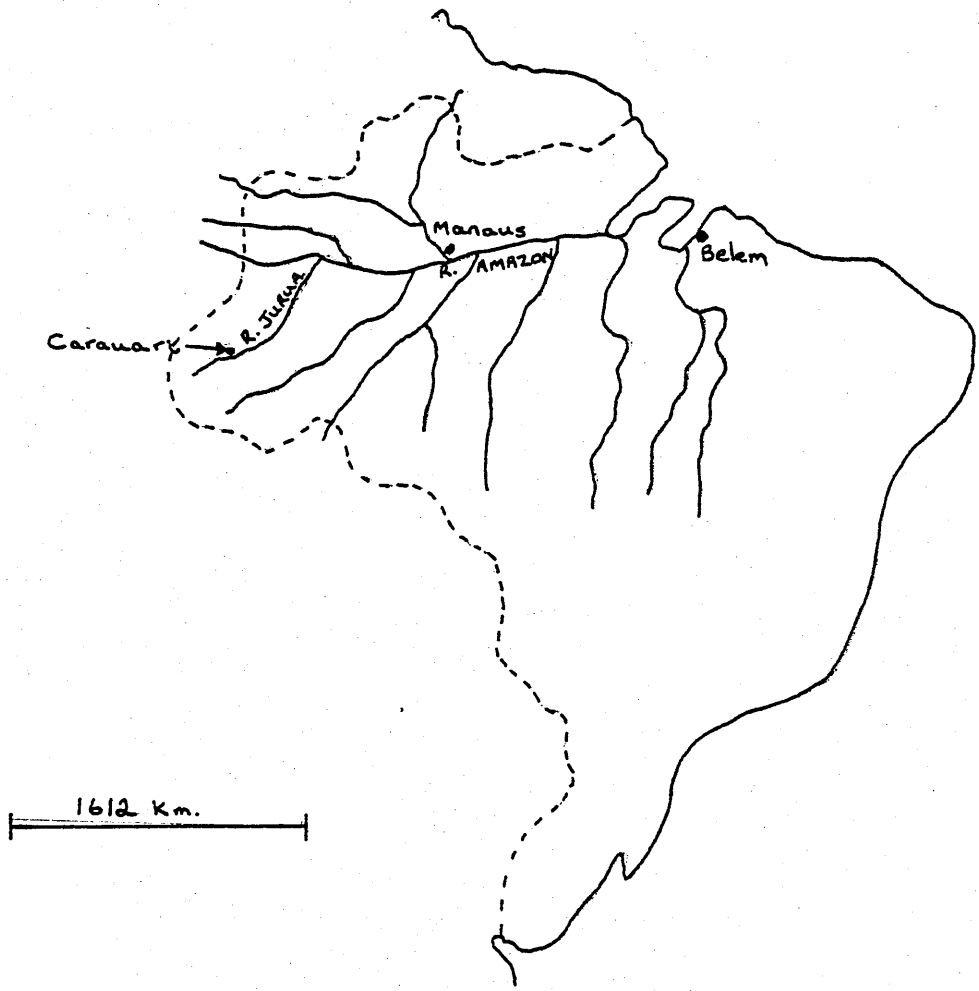
Despite visiting the country in 1977 to establish contacts with field scientists in Manaus (Amazonas) and a return visit by representatives of the Brazilian Government, great problems were encountered in importing the expedition equipment into Brazil when the expedition arrived in 1978. Thus much of the expedition's equipment, including my own apparatus, was returned to England unused. Fortunately, materials were available to build some replacements to enable a limited study to be undertaken.

Possibly even more vexatiously, we were inhibited from travelling to our intended destination which was Taraqua on the Rio Uaupes, an area Wallace found to be rich in fauna and flora. An alternative site therefore had to be chosen. The area selected was a small town called Carauari, as it was recommended as being very rich in fauna and flora by knowledgeable natives who regularly visited the region. Carauari is situated about 600km up the Rio Jurua, a tributary of the Solimoes, and is readily accessible by riverboat.

The town's position is $4^{\circ}52'48''$ South and $66^{\circ}53'34''$ West and although by river it is about 3,000kms from the mouth of the Amazon, it is only at a height of 60 metres. Its location is shown on the accompanying map.

The Rio Jurua was discovered by Pedro Teikaria, a Portuguese adventurer in the mid seventeenth century but was not extensively explored until two hundred years later when William Chardless visited

Sketch Map of Brazil to show Location of Study Area at Carauari



the area. The first settlement, by the side of Lake Carauari, from which the town gets its name, was at the end of the last century but it was not officially recognised until 1912 when the area of 27,000 square kms surrounding the town was also declared a municipality. The population of the municipality at that time was 8,000, consisting mainly of Indians of the Carauari and Catuquina tribes.

We had hoped to stay by the Jurua, but diseased water, an excess of mosquitoes and the lack of a convenient site led the advance party to choose an abandoned settlement about 10kms from the town away from the main river. It was set 20 metres back from a track running from Carauari to the next river. There was a small free-flowing stream with a pool by the camp. The site was surrounded by forest containing several rubber and hunting trails. Although seemingly dense from without we were struck by the lack of thick shrubs on the forest floor (though there were many thin saplings). This is largely due to the shortage of light penetrating the dense canopy. The canopy was at a height of 20-30 metres with a noticeable scarcity of old large trees (the so-called 'emergent' layer) but there was an enormous variety of tree types to be seen. The area was mostly flat with small depressions formed by streams.

Our site was accessible by sturdy vehicles, though few made the journey and we walked in. The trail was cleared six years ago but the edges were growing in and rains turned much of it into thick mud. We were visited from time to time by local hunters and rubber tappers passing on foot but for the most part we were left to ourselves.

We remained at our camp site (Site 2 in this study) for almost two months carrying out our research.

As a direct result of the equipment not being imported, insufficient data was obtained for this study. Fortunately a Miranda scholarship

was awarded to me in 1981 by the Anglo-Brazilian Society (London) and this enabled me to return for six weeks to the original campsite to collect more data.

1 General Introduction

One quarter of the world's fauna and flora exists in the Amazon rain forest - an area some two and a quarter million square miles in total. This climax community has remained in a 'stable' state for up to four million years. It is at present under pressure from man's activities, eg bauxite and manganese mining, cattle ranches and as a result some scientists have predicted that it will have largely disappeared by the beginning of the next century. At the present time estimates suggest that up to 70 hectares of rain forest an hour is being destroyed. This is being replanted at a rate of only 7 hectares an hour. The Amazon rain forest is reported as supporting over one million species of plants and animals. Consequent to the low rate of replanting it is often suggested that many of these species will become extinct before they have been collected and studied. Many of these species will be located living in the leaf litter and in the forest covered soil.

Despite the fact that Beebe (1916) undertook the first survey of soil fauna over sixty-five years ago, little is known about the species that inhabit soil. There is only one research station in the Amazon basin manned by about fifty scientists of varying disciplines. At the time this study began (1977) only one researcher and two students were allocated to soil organism research.

Beebe visited the Amazon basin to observe antwrens, a species of insect-eating Myrmotherula spp. He spent a week observing their behaviour in one tree. On his last afternoon, almost as an afterthought, he decided to try and identify some of the food organisms of antwrens. Beebe therefore collected four square feet of 'jungle debris'. While travelling home on a steamer he examined every leaf, stick, portion of moss, etc that he encountered. Using only a hand

lens, he captured over five hundred specimens. Beebe estimated that over five hundred specimens eluded him. Calculations then revealed that a square mile of jungle litter could contain six billion small creatures.

Over the last sixty-five years a great deal of research has been carried out into the efficiency of extraction techniques in order to quantify and facilitate the collection of small soil animals. To date, no single extraction unit is totally successful for all groups of soil animals (Macfadyen 1953, Fletcher 1976) and few techniques have proved to be effective in the remote field. Most dynamic methods, the most efficient techniques, involve a heat source and cannot be used in the remote regions of the Amazon basin. Macfadyen(1953) described an expedition multi-funnel extraction unit that used paraffin as a source of heat but this chemical is in very short supply in many parts of Amazonia. Other field extractors have been built, including those by Salmon (1946) and Belfield (1976). Both pieces of equipment required paraffin or petrol as a heat source. In addition, the portable grease film extractor of Belfield damaged specimens.

One of the aims of this study was to design and test a field extraction unit in a tropical environment. After carefully analysing the literature it was decided to construct a portable chemical extraction unit using turpentine as a repellent. This was tested in England using soil samples from oak woodland and the results obtained were compared with those from a dry heated Tullgren funnel. Data from this trial is presented in section 2.4. The results were very similar and it was therefore essential to compare both sets of results when working in the Amazon basin. This experiment is described in section 2.5.

Reliable estimates of soil dwelling populations from the Amazonian rain forest are mainly based on the work of Beck (1967, 1970, 1971). The majority of research workers have collected soil animals in order to either i) describe new species, eg Slater (1981), or ii) to determine the role soil animals play in the total energy flow dynamics of the rain forest, eg Schaller (1960, 1961), Beck (1967, 1970, 1971), Stark (1971) and Fittkau and Klinge (1973).

Two post-graduate students working in Schubart's laboratory in Manaus (1977) were known to be undertaking comparative investigations into the soil animal populations of rain forest and cleared sites in Amazonia but their results do not seem to have been published. Comparative studies have been undertaken in other tropical countries by several workers including in Nigeria, Lasebikan (1975) studying the clearance of rain forest; in the West Indies by Strickland (1945, 1947); in Surinam by Van Der Drift (1968); and in India by Choudhuri and Banerjee (1975). I therefore decided to undertake a comparative investigation into the soil animals living in a cultivated plot and those living beneath rain forests in order to observe the changes in population density brought about as a result of the destruction of the rain forest. Unfortunately, as a result of the difficulties described in the prologue, only the chemical extraction unit was used in this comparison. The data is presented in section 3.

2 A Comparison of Extraction Methods Currently Used

2.0.0 Introduction

The majority of research scientists studying soil-dwelling organisms use extraction methods that are undertaken in a laboratory in carefully controlled conditions. A survey by Fletcher (1976) indicates that most soil scientists use a dynamic method based around the Tullgren modification of Berlese's extraction unit (Tullgren 1918). The term dynamic is used by soil scientists to describe methods whereby animals leave the soil in response to stimuli such as chemical repellents, heat and light. Alternatively organisms may be attracted to stimuli. The phrase 'dynamic methods' was used by Murphy (1962), Macfadyen (1957) preferred to refer to these techniques as 'behaviour methods'. The term 'mechanical' is used by scientists to describe methods which remove animals from the soil by physical means. Fletcher (1976) also pointed out that under this heading must be included those techniques relating to the hydrophobic and oleophobic properties of the arthropod cuticle. Mechanical methods provide data on the resting stages of arthropods (eggs, pupae) which dynamic methods fail to do, but these techniques have the disadvantage of damaging specimens during mechanical extraction.

Within the tropical regions of the world both dynamic and mechanical techniques have been used. Beebe (1916) and Dammerman (1925 and 1937) used a hand-sorting technique to examine the fauna of the forest floor. Goodnight and Goodnight (1956) used handsorting and a Berlese-Tullgren technique finding the former to be very inefficient collecting only 407 specimens per square metre. Williams (1941) using a Tullgren technique collected 4,000 specimens per square metre compared to only 294 specimens when hand-sorting a square

metre. Similar techniques have also been used by others including Debouteville (1951), Strickland (1947), Van Der Drift (1968), Beck (1970, 1971), Langham (1975) and Vallejo (1981). Mechanical flotation techniques have been used in the tropics by other workers including Belfield (1958), Bullock (1964) and Salt(1952).

Some workers, (Salmon 1946, Macfadyen 1953, Belfield 1976) have experimented with field extraction techniques in an attempt to overcome many of the problems encountered in collecting in remote regions. In addition to the design of the apparatus, consideration must be given to the size of the gauze, the positioning of the soil sample on the gauze and the numbers of samples to be collected for statistical analysis.

To date, no extraction technique can claim one hundred per cent success in extracting organisms from all groups. It is critical to consider in relation to the environmental conditions of Amazonia the techniques that might be used in the field in order to select the extraction unit with the highest efficiency in conditions of high temperature and humidity. At the same time it must not be dependent on a source of power or other facilities only available in a laboratory.

2.1 Laboratory Extraction Techniques

2.1.0 Introduction

Many different techniques for capturing soil animals have been developed since the beginning of this century. Since the end of the second world war many research workers have carried out comparisons of two or more extraction techniques in order to determine the most efficient method. Early comparisons included those of Ladell (1936), Van Der Drift (1951), Macfadyen (1953 and 1961) and Kuhnelt (1961). Murphy (1962) carried out an extensive review of the then current extraction techniques. More recent comparative studies have been undertaken by Kikuzawa et al (1966), Southwood (1966), Vannier (1970), Wallwork (1970), Huhta (1972) and Marshall (1972). Fletcher (1976) conducted a survey amongst research workers prior to carrying out an extensive comparative study of 11 different extraction techniques.

He pointed out that one of the major problems in comparing soil animal extractors lay in determining their extraction efficiency. One can never be certain that absolutely every specimen in the sample has been collected. 'Seeding' soil samples does not solve this. Macfadyen (1962) pointed out that although animals were added to the soil they may well not emerge due to factors such as damage during handling or to changes in the chemical structure of the soil resulting from sterilisation techniques. This 'changing' of the soil caused the fauna orientation problems. In addition sterile soil is unable to support life, (Kempson 1963).

Initially extractors were developed primarily to obtain soil fauna for taxonomic studies. Later on their use became

adapted for quantitative collections with varying degrees of success.

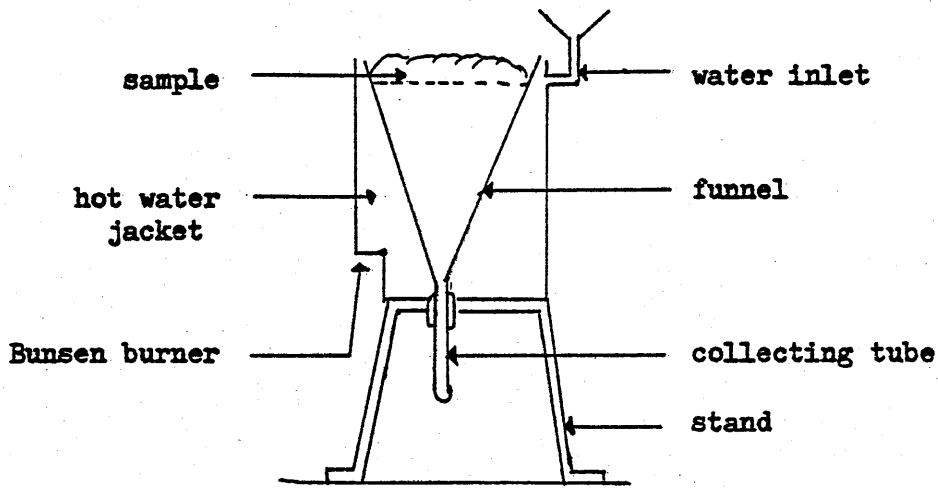
2.1.1 Dynamic Methods

Anton Berlese (1905) devised one of the earliest dynamic extraction techniques. A dynamic extractor causes fauna to leave the soil in response to physical and chemical factors that may attract or repel. Berlese's apparatus consisted of a funnel fitted with a gauze. The funnel was encased in a water jacket that was filled with warm water. Specimens fell into a vial containing alcohol beneath the apparatus (Figure 1). The most significant modification of this apparatus was made by Tullgren in 1918. Three years earlier Krausse (1915) had removed the water jacket replacing it with a water bath that could be heated both around and above the sample. Tullgren replaced the water bath with a light bulb suspended above the sample (Figure 2). This dry funnel apparatus is still used by many soil scientists today, (Fletcher 1976).

Most dynamic methods since the early part of this century have incorporated Tullgren's modification. Extractors commonly used include Murphy's split funnel extractor (1958), Macfadyen's high gradient canister extractor and his air-conditioned funnel extractor, Valpas's hot rod technique (1969) and Kempson-Lloyd and Chelardi's infra-red extractor. Fletcher (1976) showed that despite the different techniques available a great many soil zoologists still relied upon a simple heated Tullgren funnel.

Macfadyen (1961) has described and tested many different types of extraction unit. Both of his more recent designs have incorporated features to ensure that steep temperature

Fig 1 - Berlese Funnel Apparatus (Berlese 1905, after Vannier 1970)



and humidity gradients can be maintained during extraction. He believes these two factors to be the most important stimuli causing the taxic responses of soil organisms. This has now been widely accepted. Haarlov (1947) was one of the first workers to appreciate the importance of temperature and humidity gradients. He modified his funnel to prevent the loss of animals which became stuck in the condensed water on the sides of the funnel. This involved leaving an airspace between the funnels and tubes allowing a circulation of fresh air within the funnel. Forsslund (1948) demonstrated that as a result of condensation soil organisms emerged in two groups; initially as a result of temperature and finally with reduction in moisture content until the completion of drying. Macfadyen (1953) designed his apparatus to incorporate some of the features of Haarlov's apparatus. His high gradient funnel (Figure 3) exhibited a gap of one quarter of an inch between the funnel and core to prevent condensation. The glass funnels had sides with a included angle of 60°. A plastic insulation baffle was used to create a steeper temperature gradient. The unit in all contained 30 funnels. One of its advantages was the fact that it created a temperature gradient of 8°C from top to bottom of the sample. As a result 100% more Collembola and 50% more mites were collected when compared with a standard Tullgren funnel's performance using an identical sample.

Macfadyen (1961) further modified this apparatus by replacing the funnel with a canister of the same diameter as the sample tubes. This is referred to as a high gradient canister extractor. Its most important features include a mild steel

Fig 2 - The Tullgren Apparatus (Tullgren 1918, after Vannier 1970)

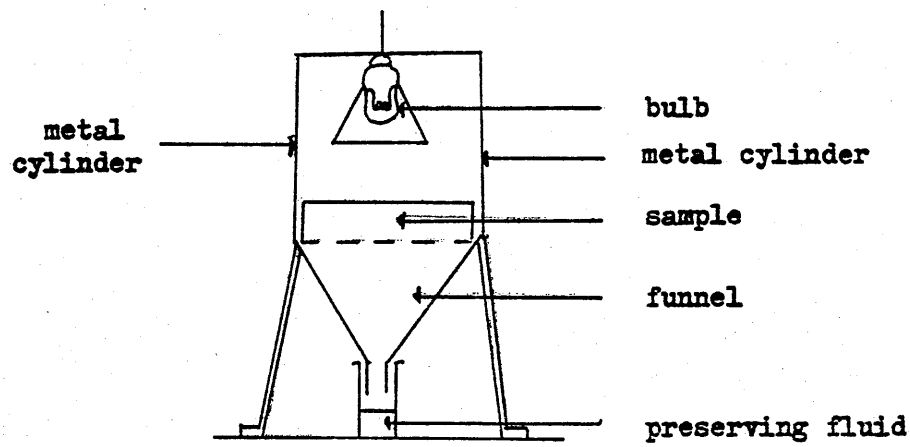
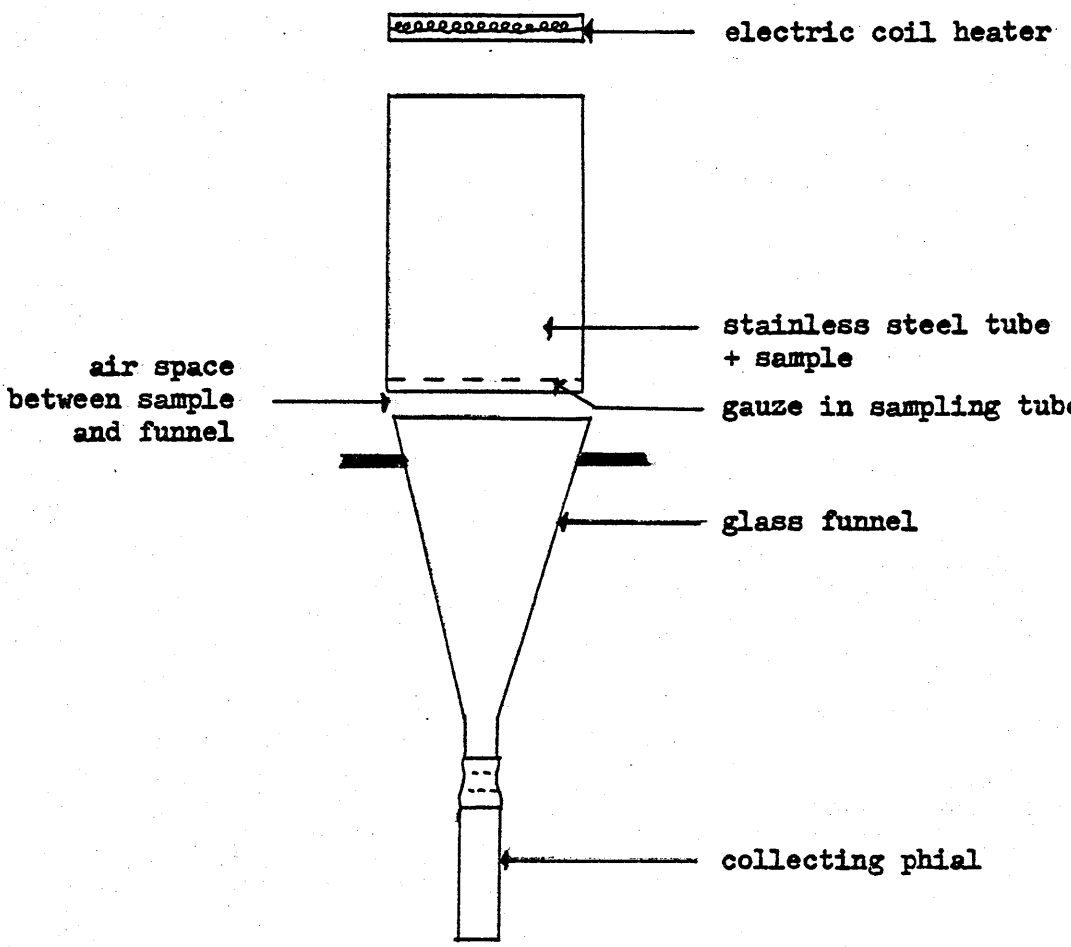
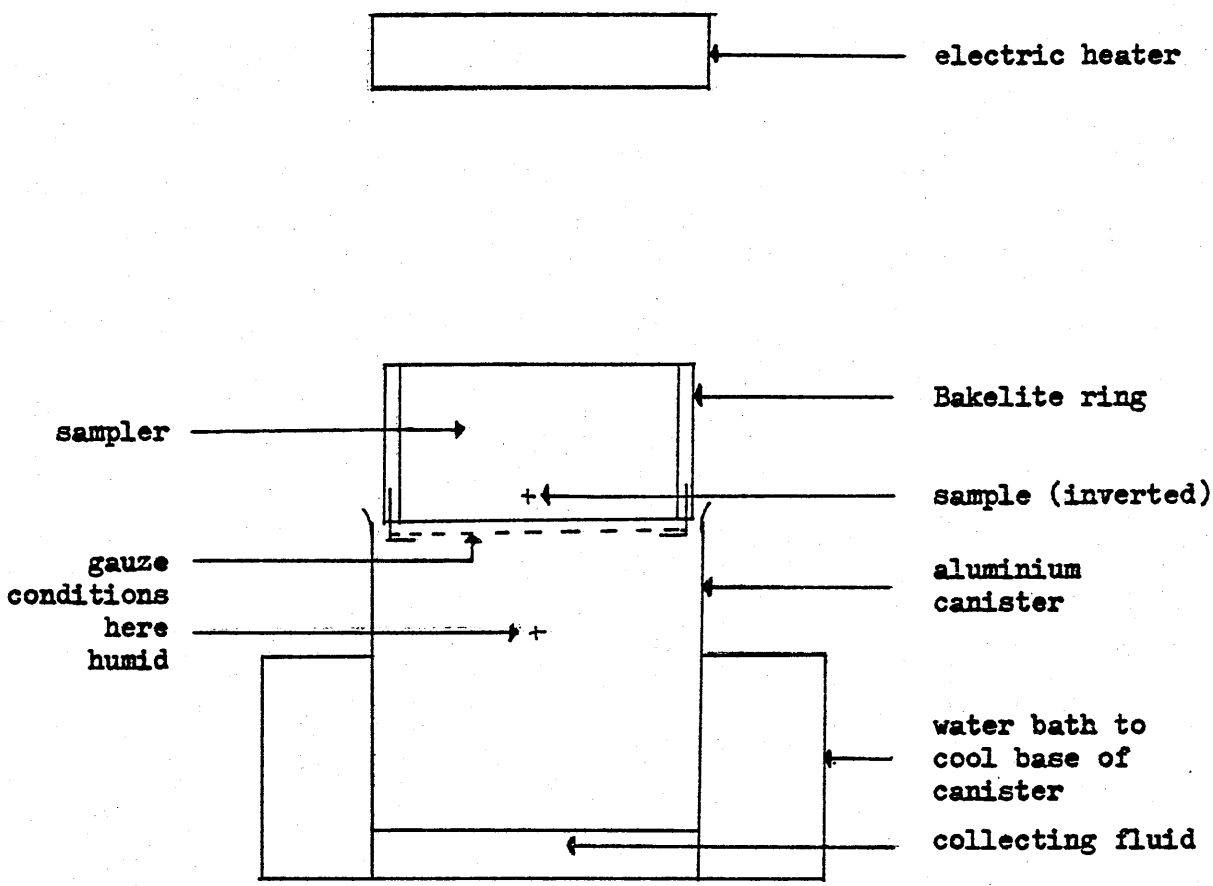


Fig 3 - The Macfadyen 'high gradient' funnel (after Macfadyen 1953)



sampling tube containing bakelite rings that are used to hold the sample in place in the extractor and the sampler. The funnel has been replaced by an aluminium canister that fits into the bakelite ring (Figure 4). The base of the canister can be cooled by a water bath whilst the upper surface is heated. Cores are placed in an inverted position in the extractor. Conditions beneath the soil sample remain humid throughout the experiment. This together with a temperature gradient of 20°C from top to bottom of the sample (a distance of 3cm) prevents condensation. Hale (1964) further modified this apparatus by reducing the surface area of the soil from $50cm^2$ to $11.35cm^2$. Marshall (1972) used a modified version of this apparatus (Auerbachs and Crossleys 1960) and found its efficiency to vary according to the habitat being sampled. Kempson et al (1963) found it to be between 95-99% efficient when extracting Acarines. These results were slightly better than those achieved by Marshall (1972). Block (1966) returned a recovery rate of 76% for Acarines after making known introductions of specimens to mineral soils. Merchant and Crossley incorporated modifications into a high gradient extractor (1970). Seadstedt and Crossley (1979) found the apparatus to be inefficient under conditions of high humidity (ie somewhat equivalent to the Amazon rain forest). High humidity resulted in high levels of condensation on the funnel sides. However this extractor proved to be more efficient than canister collectors and Tullgren funnels. Fletcher (1976) found his modified high gradient canister extractor produced relatively poor results compared to other extractors tested in his comparative study. He came to the conclusion that great

Fig 4 - The Macfadyen High gradient canister extractor
(After Macfadyen 1961)

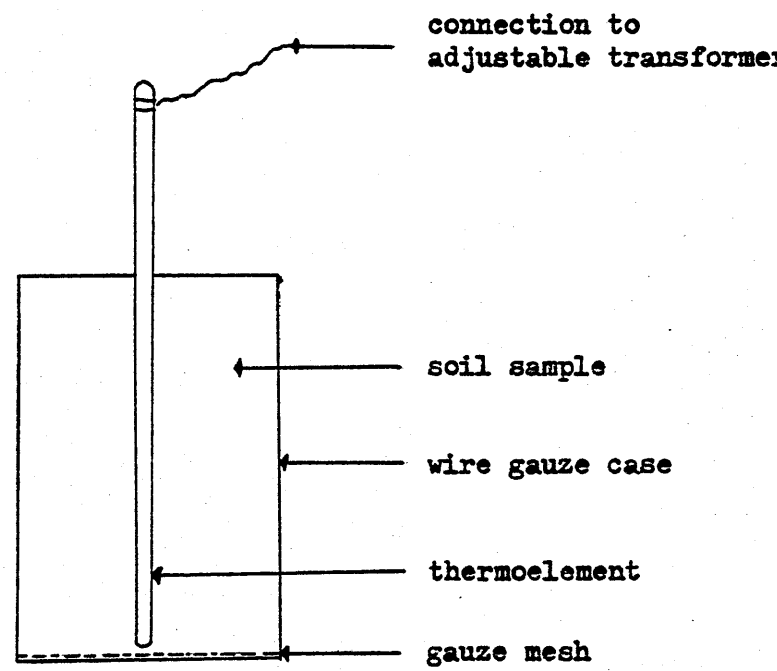


care in using it must be taken, particularly when establishing the ventilation across the base of the soil core to prevent condensation. Bieri et al (1979) modified Macfadyen's high gradient apparatus by changing the materials incorporated in the lower cooling system section. This resulted in the apparatus having an efficiency of 90%. Takeda (1979) compared the efficiency of the high gradient extractor with both direct counting and hand-sorting techniques. He found it to be only 28% efficient in the summer and 88% in the winter. Petersen (1978) compared both the high gradient funnel and canister extractors with a salt water centrifugal flotation technique of Muller (1962). Macfadyen's apparatus's both proved to be between 80-90% efficient for Collembola and 90% efficient at extracting Cryptostigmata and Mesostigmata.

Valpas (1969) modified the dry funnel technique by inserting a therme-element into the soil core. This is known as the 'hot rod' technique, (Figure 5). As the temperature of the rod increased so a temperature gradient was established. Valpas compared this technique with Macfadyen's high gradient cylinder and found there to be no significant difference in the efficiency of the two. Fletcher (1974) was able to demonstrate that Macfadyen's apparatus was the more efficient although again this was dependant upon the soil type. Huhta (1969) showed that the efficiency of the hot rod technique declined as the diameter of the soil core was increased.

Macfadyen (1961) also developed an air-conditioned funnel extractor. This was originally designed for obtaining specimens from loose or stony ground. In this apparatus samples are electrically heated from above whilst at the same time establishing a good flow of air to ensure rapid drying of the sample. The lower part of the sample is seated in a separate chamber in which cooler air at 8°C is

Fig 5 - Valpas's 'hot rod technique' (After Huhta 1972)



circulated once it has passed over a humidifier. He found that 95% of all the animals were extracted within 6 days using a 40W element. In fact, this apparatus was shown by Macfadyen to yield from 2-10 times more animals than the standard Tullgren technique. In his comparative study, Fletcher (1976) found that of the 7 dynamic methods he tested the air conditioned funnel was overall the most efficient technique.

Other dynamic methods worthy of mention include Kempson et al's (1963) Infra-Red extractor. The wet funnel technique of Baermann (1917) is useful when extracting nematodes. Goddard's (1979) modified Tullgren apparatus replaces a funnel with a collecting bowl and proved to be 70% efficient when extracting Pseudoscorpiones.

In conjunction with the selection of the type of extractor to be used for any particular study, further consideration should be given to factors, other than temperature and humidity gradients, that affect the efficiency of the extraction process. These factors have been summarised by Kikuzawa et al (1967) as follows:-

1. Selection of sample site
   a) Heterogenity of environments → 2a), 2b)
   b) Aggregation of animals → 2a), 2b)
2. Sampling
   a) Sampling size and unit area → 2c), 2d), 4a), 4g)
   b) Sampling depth → 2c), 2d), 4g)
   c) Structure and size of samplers → 3b)
   d) How to take soil samples → 3b)
   e) Season, weather and hour of sampling → 1b)
   f) Personal variations in sampling → 2d)
3. Transportation and preservation of samples
   a) Time from sampling to extracting → 3c)

b) Container for transportation and preservation → 3c), 4k)

c) Vibration, change of moisture and temperature during transportation

4. Extracting

a) Size and structure of funnel → 4e), 4f)

b) Arrangement of funnels → 4c)

c) Heat sources: kind and intensity of heater and the distance from the sample material → 4h), 4j), 4k)

d) Mesh size of sieve in the funnel → 5a)

e) Escape and invasion of animals during extraction

f) Entrapping of animals in dew drops condensing on the inner wall of funnels

g) Nature and quantity of the sample material→4c)

h) Duration of extraction

i) Repellent effects of liquid in the collecting vessels → 4e)

j) Room temperature in which the apparatus is set → 4e)

k) How to put soil materials into funnel

5. Sorting

a) Mistaking animals for plant debris and fine sands and vice versa

b) Oversight of minute animals

c) Mis-classification of animals

The factors mentioned above correlate with each other and the arrows show their influence upon the other factors.

It is important to take great care when 'handling' samples. The importance of using the correct type of sampling tool is discussed in another section (page 55). It is however important not to compress the sample when obtaining the core (Macfadyen 1961). Hughes (1955) soaked his soil samples in water prior to extraction in order to prevent too rapid desiccation of fragile samples which would trap soil

fauna within the sample. Hammer (1944) pointed out that better extraction results could be obtained by inverting soil samples in the extractor. Niijuma (1967) on the other hand, broke his samples up prior to extraction. Macfadyen (1953) and Fletcher (1976) both showed that inverted samples yielded significantly higher faunal numbers.

Murphy (1958), Healey (1962) and Berthet (1971) are just three of the many soil zoologists that have shown that the size of the core and the depth of sampling also affects the number of fauna extracted from a sample. Fletcher (1976) pointed out the advantages of taking several smaller samples rather than one large sample from a site. The deeper the sample the less fauna will be collected and therefore the less accurate the population estimation (Strickland 1945). Southwood (1966) has also pointed out that the seasonal variations will also affect the population estimate. Dammerman (1925 and 1937) was able to demonstrate in the East Indies that a population peak was reached at the height of the rainy season. This has been confirmed by Williams (1941) working in Panama and by Strickland (1947) working in the West Indies to name but two. The latter also demonstrated that as the dry season advanced so the Acarina and Collembola migrated downwards through the soil; the decline in percentage terms was 38% in a cacao plot and 50% in savannah. This movement appeared to be in response to the decreased rainfall and humidity.

Reca and Rapoport (1975) demonstrated that the size of the mesh used in the Berlese-Tullgren funnel significantly affected the results. For a highly organic soil in a temperate climate the greatest extraction efficiency was achieved using a gauze with holes 4.5mm across at which size 90% of the total fauna was collected. Using an identical technique but a 2.3mm gauze, only 70% of the total fauna

was collected.

Merchant and Crossley (1970) devised a simple and inexpensive extraction unit based in an old refrigerator and designed along the lines of a high efficiency Tullgren unit. Each funnel unit incorporated a Christmas tree light bulb as a heat source and this was situated above the sample. They also undertook experiments to determine the effect of different coloured light on the extraction of soil fauna. Three samples were placed under bulbs, each of the following wavelengths of light: blue, green, yellow, red, white and clear. Controls were set up without light and heat. No significant difference in the efficiency of extraction was detected. They did however, recommend the use of white bulbs.

The collecting fluid to be used in the collecting tubes of an extraction unit must also be carefully selected. Some fixatives have a strong smell and in a confined space will repel or attract fauna, (Macfadyen 1961). In addition, some chemicals corrode the aluminium containers, eg Phenyl - mercuric acid. This chemical would be extremely useful as a preservative if an alternative to aluminium collectors could be found. Macfadyen also pointed out that Glycine caused animal handling problems in that specimens were difficult to see and remove, whilst distilled water did not prevent the growth of mould. Fletcher (1976) reported that many soil zoologists used ethyl alcohol as a collecting fluid although Macfadyen (1961) had earlier concluded that this chemical could not be used safely in confined spaces. Kempson et al (1963) recommended the use of picric acid solution. As can be seen, in the past 20 years a wide range of chemical solutions have been used and compared as collecting fluids; these include picric acid, ethyl alcohol, ethylene glycol, carnoy's liquid and chloral hydrate.

As a result of a questionnaire sent to 150 soil zoologists throughout the world, Fletcher (1976) carried out an experiment to compare the effects of the three most commonly used collecting fluids on the number of soil arthropods which could be extracted from a silt-clay loam soil. His results, obtained using Rothamsted funnels showed that many more animals were collected into alcohol and picric acid as opposed to distilled water. There was no significant difference between the results obtained using picric acid and ethyl alcohol, although greater numbers were collected into the picric acid solution. Macfadyen (1968), Kempson et al (1963) and Lussenhop (1970) all preferred to use picric acid as the collecting fluid despite the staining of skin, hands and specimens. Macfadyen's (1961) results, using his canister apparatus showed on the other hand that more animals were collected into distilled water. This would appear to disagree with Fletcher's results described above. Fletcher considered this apparent difference and concluded that the differences were due to the different construction of the two extractors. In the confined space of Macfadyen's apparatus, arthropods could be killed by a high concentration of vapour, whereas the Rothamsted funnels created a less concentrated vapour that could act as an attractent or repellent. Therefore when designing a new extractor, tests should be undertaken to determine the most effective collecting fluid. When collecting samples from remote regions away from the laboratory extractor; or when collecting very large numbers of soil samples for extraction, samples may be stored for a varying amount of time. It is therefore important to consider the implications of storage on the soil fauna and hence population estimates. This is of less importance when considering mechanical extraction techniques when fauna both dead and alive will be collected whether or not they have

become trapped in dried soil clumps. Similarly soil may be safely stored at low temperatures, eg 1-2°C prior to mechanical extraction but this method is not suitable for dynamic methods as low temperatures will kill many soil-dwelling animals. At higher temperatures the community of the soil fauna will continue to live and die within the sample (Fletcher 1976), and new animals will hatch from eggs laid in the soil. Hughes (1955) discovered that the longer he stored samples prior to dynamic extraction the longer it took to extract Collembola from the sample. However, the total number of Collembola collected was not significantly affected by storage. Murphy (1958) found that if samples were stored for 12 days it resulted in a reduction in the number of Acarines collected from a sample. Sheals (1964) found that if samples were retained in tins with tight fitting lids for three days this had no adverse effect on the soil community within them. Fletcher (1976) found that samples could be safely stored for up to 4 weeks without significantly affecting the numbers obtained using dynamic extraction techniques such as a dry Tullgren technique.

2.1.2 Mechanical Methods

An alternative means of extraction to dynamic methods considered in the previous section are a group of methods referred to as being mechanical. Mechanical that is in the sense that the soil animals are removed by physical methods that do not rely on the animals' responses to stimuli. The techniques of this type most commonly in use are hand-sorting, flotation and grease film extraction. These methods are only briefly considered below as they were not seriously considered for use in the Amazonian rain forest as they generally entail the transport of large amounts of material.

Hand-sorting is an inefficient technique. Beebe (1916) hand-sorted

four square feet of Amazonian litter whilst returning to America on board a steamer. He collected 500 specimens and estimated that one thousand remained unseen or had evaded capture by hopping away, eg Collembola. Today hand-sorting is only used to compare the effectiveness of a new technique. Fletcher (1976) in fact found that only three of the one hundred and fifty soil zoologists surveyed employed this technique.

A considerable number of flotation techniques have been devised and subsequently adapted by other workers. One of the first flotation techniques to be used was devised by Berlese (1921). His technique involved the use of saturated sodium chloride solution to separate soil fauna extracted from debris using a Berlese funnel. This technique has been improved and was used by Fletcher (1976) as one of the two techniques in his comparison. He added samples to sodium chloride and mixed the two to form a suspension. The floating material was then passed over a 150/inch mesh sieve. Collected material was then washed in water prior to the addition of xylene and the formation of a water-xylene interface which was examined for soil organisms. His results using this technique were not as good as those from the grease film and dynamic extraction methods.

Other mechanical means available include wet sieving techniques. Morris (1922) designed one of the earliest models which consisted of a series of horizontally stacked graded mesh sieves (Figure 6). Soil samples were washed through the sieves which held back larger debris and fauna. The soil particles were washed away in solution. The sieves were then examined for organisms. Ladell (1936) devised a mechanical technique that forms the basis of many of the mechanical techniques in use today. His apparatus was designed to carry out an initial flotation followed by a washing technique. This technique was

Fig 6 - Morris's Wet-sieving apparatus (Morris 1922, after Vannier 1970)

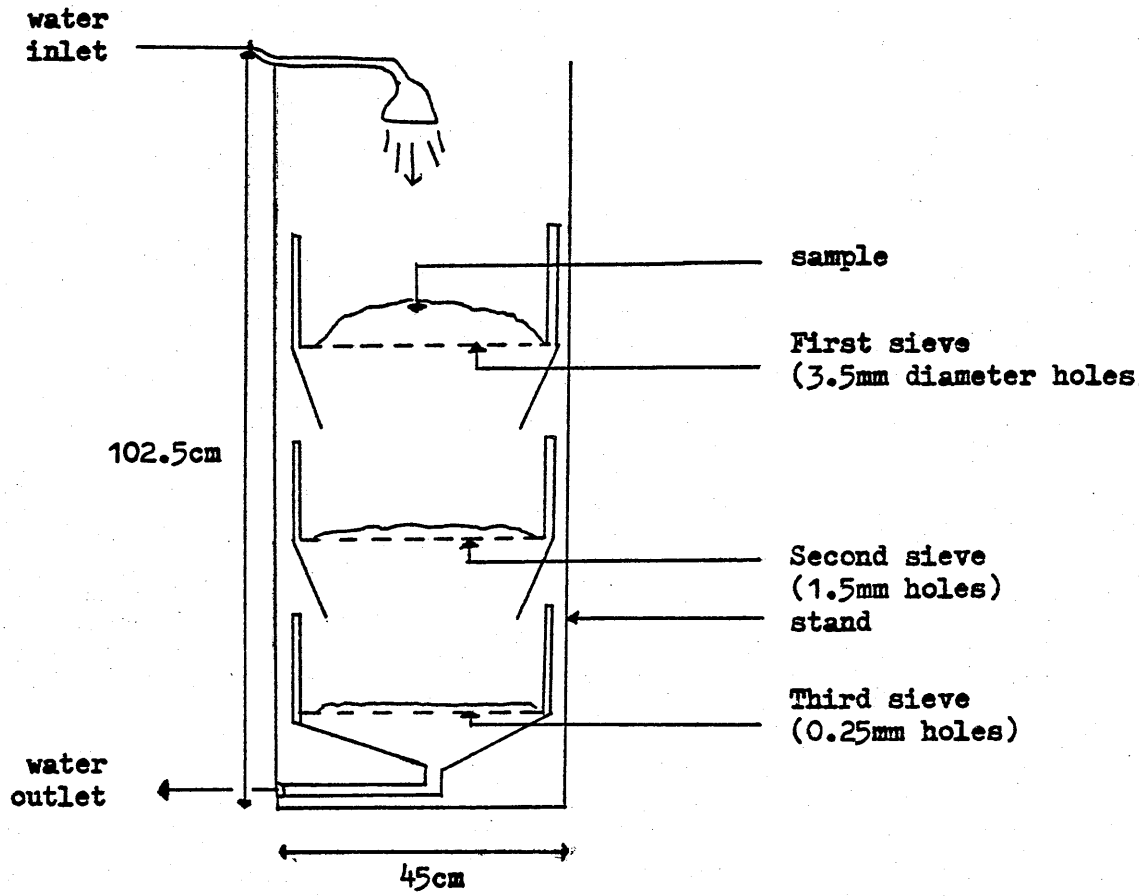
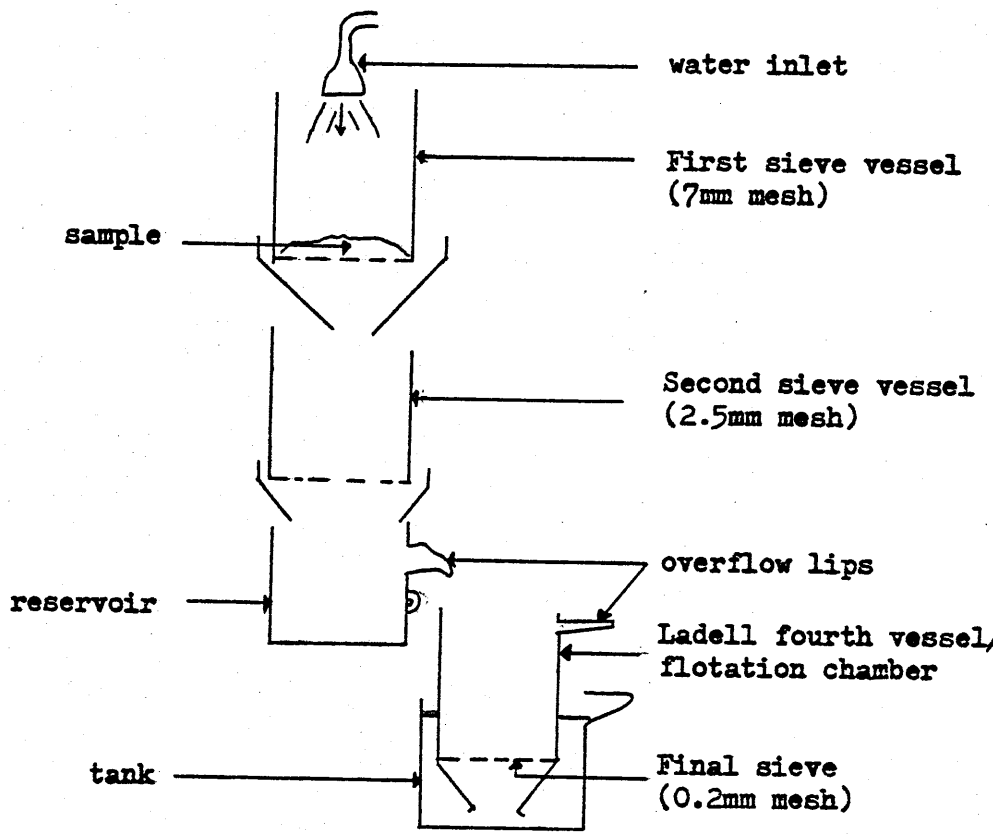


Fig 7 - Salt and Hollick apparatus for wet sieving (Salt and Hollick 1944 after D K McE Kevan 1962)



modified by Salt and Hollick (1944) in order to extract wireworms from soil (Figure 7). The technique consisted of two main parts. Initially samples were washed through two sieves into a container. Material was removed from each mesh and carefully washed and separated. The remaining material containing soil fauna was washed into the container. This incorporated an overflow into a Ladell container. Thus as water flowed into the container excess water and suspended organisms were overflowed into the Ladell container. This second container has a mesh fitted into its base and a drain pipe to remove excess water and suspended soil. At the completion of washing the second phase of Salt and Hollick's process was commenced. This consisted of adding magnesium sulphate solution to the Ladell container. The contents were mixed using compressed air. This caused the organisms to float to the surface. These were decanted via a tube with bolting silk into another container where the decant was mixed with a solution of Benzene (this has now been replaced by Xylene and other chemicals), creating an interface which was examined for animals which could then be removed.

Raw (1955) is only one of many who have modified Salt and Hollick's technique to make it useful for collecting soil arthropods. Macfadyen (1953) found Salt and Hollick's process to be at least as useful and efficient as funnel methods for extracting larger insects but less efficient at extracting mites and springtails. He found it difficult to separate small animals from the litter particularly if their bodies were covered in hairs, eg many mites. In addition Macfadyen found that the mechanical technique took up to ten times as long to complete as did the Tullgren techniques and hence involved more man hours. Other modifications of the Salt and Hollick process have been undertaken by Macklin et al (1957), Fenney (1967),

Stewart (1974) and Edwards et al (1970) and D'Aquilar (1957) who prior to treatment, removed larger stones by washing his samples through a coarse sieve. He used potassium bromide as a flotation chemical. In fact most of the modifications to the Salt and Hollick apparatus have been to the flotation part of the extraction.

Muller (1962) devised a salt water centrifugal flotation technique. To a sample, a saturated solution of sodium chloride was added, followed by centrifugation for three minutes at 1500 rpm. The supernatant was then examined for fauna. Petersen (1978) found the supernatant contained too much debris and introduced a benzene flotation based on the work of Raw (1955). Even after this improvement he found the technique to be less efficient than the high gradient apparatus of Macfadyen (1961).

Suleman et al (1979) found that a mechanical technique using dry sieving followed by flotation proved one and a half times more efficient than a Tullgren technique for all groups except Collembola.

Lawson (1978) modified Ladell's apparatus in order to extract organisms from wetlands. Soil and litter samples were immersed in magnesium sulphate, agitated and bubbled followed by a salt solution recycling phase. This proved to be 80-100% efficient. Fisher (1980) also adapted the soil washing phase and the differential phase in order to collect corn rootworm larvae with a success rate of 93.4%.

Bergeman (1982) compared a washing, sieving technique with a Tullgren technique in order to find the best means of collecting corn rootworm larvae. His results confirmed those of Fisher. Mechanical methods proved much more efficient.

Other mechanical techniques have included a grease film extractor as devised by Aucamp and Ryke (1964). This is discussed in detail in the next section (page 44). Wallace (1972) described a suction

technique developed by Curry and O'Neill (1979) who examined the arthropods beneath various swards using the D-vac suction system. Anderson and Healey (1970) 'froze' soil blocks with gelatin prior to slicing thin samples and examining them for soil fauna. Seastedt et al (1980) simplified and improved the gelatin embedding technique which is useful in that it provides a different visual perspective that is not available when using funnels. It also provides an opportunity to examine the vertical stratification of organisms in the sample.

De Wolf and Buth (1981) devised a simple method for separating fauna from litter fractions. They developed a system of 3D sieving followed by the separation off of plant litter using a strong jet of water.

2.2 Field Extraction Techniques

The collection of soil organisms in remote areas followed by extraction in the field poses many problems. These have been highlighted by Sheals and Hyatt (1963).

One of the problems encountered in such field studies is that few taxonomic studies of soil organisms exist. Thus there is a high probability that many of the collected species will be unlisted. Hammer (1958) collected one hundred and twenty-nine species of Oribatid mites in Argentina and Bolivia. One hundred and sixteen species were new to science. Delamare and others (1962) also identified many new species when studying their collections from South America. Thus Schubert (personal communication) studying mites in Amazonas has collected many new species, most of which still remain to be classified. It is therefore important to collect in remote regions sufficient specimens for systematic study. Many areas

prove to be difficult to return to through lack of permits, finance, time, etc. It is of course important to collect as many stages of the life cycle as possible. This entails recurrent sampling. Fletcher (1976) used sixteen samples to provide a mean for his study involving the comparison of extraction techniques, whereas Lasebikan (1975) studying the effect of clearing on soil arthropods in Nigeria collected ten samples from each site studied.

A major priority when working in remote and isolated regions is the extraction technique to be used. It is important when deciding this to be aware of the limitations of each technique, and to be aware of the 'local' conditions. In my own case this involved an initial trip to Amazonas to 'see the lie of the land' and to talk to experts at INPA (Manaus), the only research station in the whole of the Amazon basin.

Thus, some considerable thought went into the choice of apparatus. Trials were carried out in England using a variety of techniques. Since the site of the study was linked to an expedition working in an isolated region amongst Amazonian Indians - an area where contact with 'civilisation' was unlikely for three months, particular consideration had to be given to a unit that would be light in weight, that would not be difficult to service. In addition it must not operate on electricity or use up large amounts of fuel or chemical solutions.

Salmon (1946) was one of the first researchers to design an apparatus for use in the field. This consisted of a chromium-plated funnel having a waterbath heated lid. Heat in the field was provided by a spirit lamp. Extraction was by dynamic means. When the lid was maintained at 80°C with an atmospheric temperature of 18°C, Salmon discovered that extraction of Collembola was completed from a 'small'

measure of leaf litter in twenty to thirty minutes. Sheals and Hyatt (1964) doubted that this apparatus would be useful in quantitative studies.

Hyatt together with Evans and Browning has devised a collapsible polythene funnel (Fig 8) which can be hung from trees. It incorporates a folding frame. It is simply constructed and easily portable. Unfortunately hanging from a tree it is likely to sway and experiments in this country suggest that samples of soil fauna will become heavily contaminated with debris. The direct result of that is additional time when sorting specimens. Hyatt then proceeded to develop the use of standard mass-produced funnels which proved adequate (1978 personal communication).

Macfadyen (1953) described an expedition extractor, using paraffin as a heat source, (Fig 9). The design was such that thirty small (10 sq cm) samples could be extracted at one time. He allowed no air space between the stainless steel sampling tubes and funnels resulting in condensation problems. Sheals and Hyatt (1964) pointed out that although stainless steel sampling tubes are ideal when working on peat and mineral soils they were unsuitable for forest litter. The design of the apparatus was such that the sides of the funnels were steeply sloping and incorporated the high gradient principle ensuring a definite temperature and humidity gradient. Extraction was completed within three days. This apparatus, although portable, used samples of relatively small size that would be of little use for quantitative studies. Increasing the size of the sampling apparatus would remove its portability. In addition, condensation problems would cause animals to stick to the sides of the funnel. The apparatus would be more acceptable for field use where the collection of species of particular types for systematic study were

Fig 8 - Collapsible Polythene Funnel (after Oldroyd)

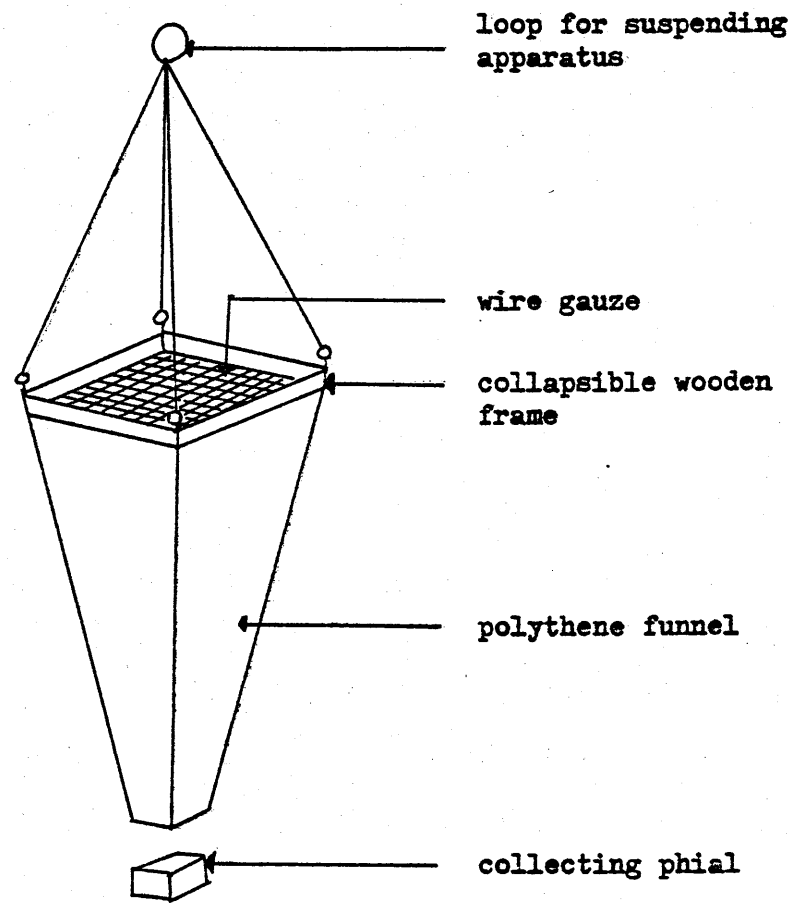
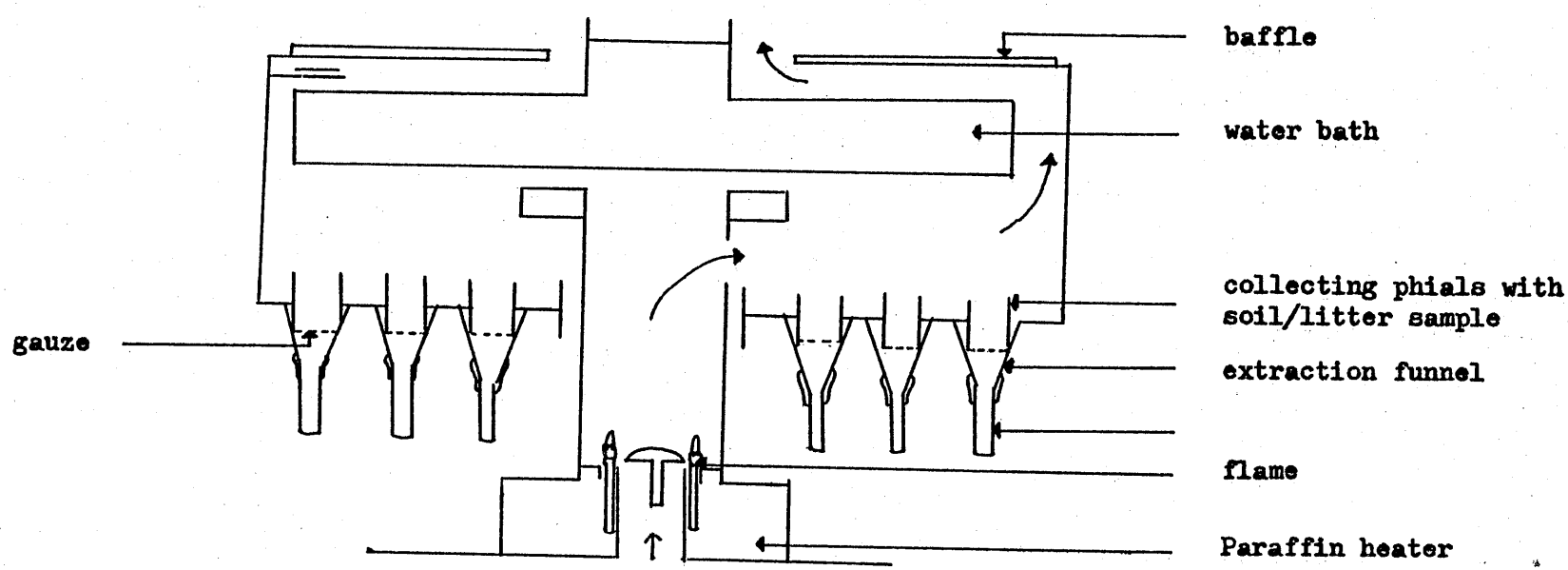


Fig 9 - The Macfadyen 'Expedition' Funnel Apparatus (after Macfadyen 1953)



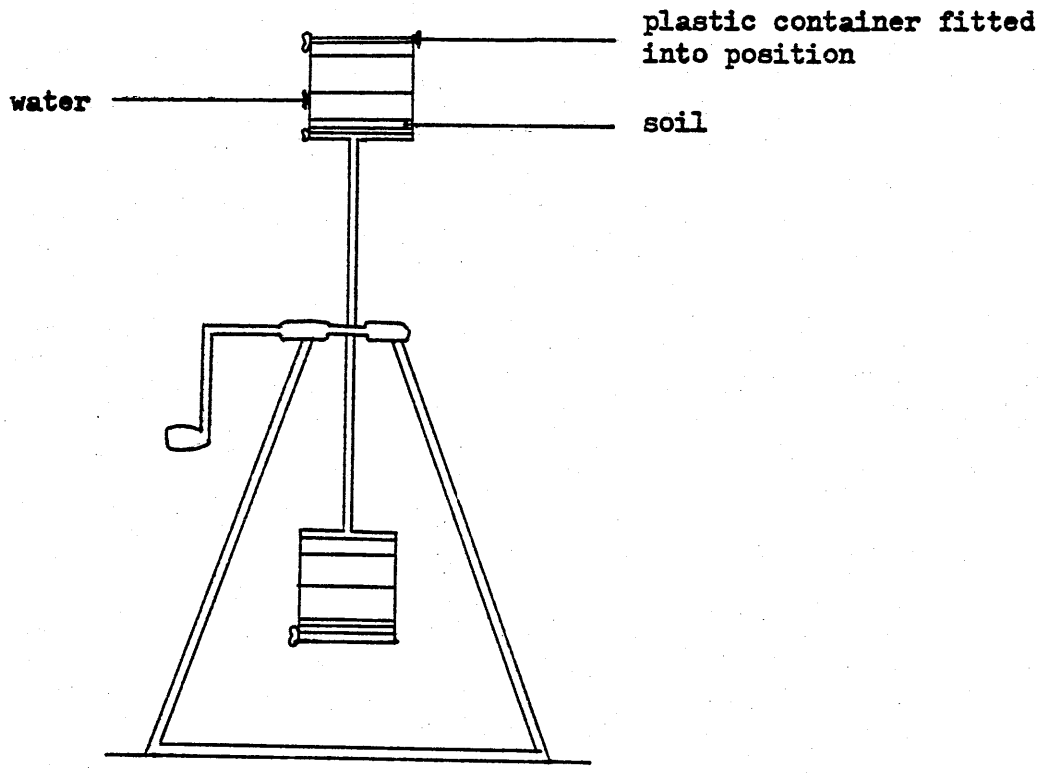
Vertical Section

needed. The apparatus would be most useful in extracting species from a large number of small samples in a situation where the more samples 'run', the greater the number of a particular species obtained.

Aucamp and Ryke (1964) produced a preliminary report on a new extraction technique which has since been fully developed and modified by many workers. The grease film extraction technique was designed to function along mechanical lines. It was constructed and designed to produce higher yields of animals per sample whilst at the same time being less time consuming and less expensive than the Berlese-Tullgren funnel methods and the flotation of Ladell. It is based upon the principle that most arthropods are not wettable and in a water medium stick to grease. The apparatus was originally constructed using a square plastic tank (10cm x 10cm x 10cm). It was fitted with two false and detachable sides that slotted into the inner surfaces of two sides. Each false side was engraved with a grid of 5cm to facilitate the counting of animals. These sides were coated with a thin layer of lanolin. An important feature was a tight-fitting sealed lid. A pair of identical tanks were fitted to a rotating arm mounted on a stand. The tanks were rotated so that the soaked soil in the tanks (as a water based mixture) passed over the lanolin coated surfaces (Fig 10). This was carried out for ten minutes. The greased plate was then removed and gently washed to remove debris. The plates were then examined and the animals removed and cleaned in carbon tetrachloride. In 1965 Aucamp and Ryke using 'seeded' soil samples were able to demonstrate the efficiency of this technique. This was one hundred percent for oribatid mites. The lowest yield was for Uropodina - seventy percent return.

Belfield (1976) adapted the grease film extractor for expedition use.

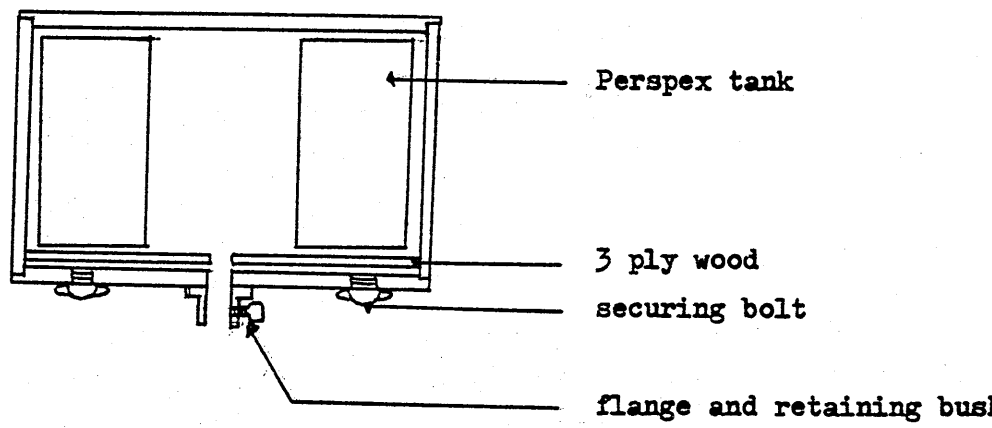
Fig 10 - Aucamp and Ryke's Grease Film Extractor (after Aucamp and Ryke 1964)



It consisted of a small wooden box of inside dimensions 23 x 36cm with a depth of 23cm (Fig 11). In the centres of each of the long sides a hole of 1cm diameter was drilled. To one side a flange and retaining bush was fitted. To the other side a piece of ply with a matching hole was fitted. The ply was used to hold the four plastic boxes in position. The turning handle rod passed through the bored holes. The plastic boxes were of similar design to those of Aucamp and Ryke. Belfield discovered that the best results were obtained when the box was rotated four times per minute for ten minutes. The apparatus is easily assembled and the technique ensures a rapid extraction process - an important asset when working in a remote area for a short time only, as when resting during a jungle trek. In addition Belfield devised a suitable field technique for the collection of trapped animals and their subsequent storage. Immediate examination of the animal-lanolin coated surfaces is not always practical when working in the field. He soaked the grease-coated plates (or vaseline coated) for ten minutes in petrol in a shallow dish. After this time any remaining grease on the plate was washed through a 12cm diameter funnel closed with bolting silk at the base of the funnel. The petrol in the dish was then passed through the funnel. The dish and funnel were then washed down with petrol followed by pickling fluid. The bolting silk complete with specimens was then preserved.

Belfield pointed out that diesel fuel and paraffin could be equally well used without damage to the specimens. Both solvents recovered all the 'seeded' specimens from the grease plates. Fletcher (1976) found that organisms extracted in this way were often damaged and that one could not distinguish between animals captured live and those dead prior to extraction. For a study in a virgin area it was

Fig 11 - Belfield's expedition grease film extractor (after Belfield 1976)



Horizontal Section Through Box

important to collect intact specimens which might prove new to science. In addition supplies of fuel suitable for use as a solvent were uncertain, any available paraffin being used for lamps. During his comparison of eleven different extraction techniques, Fletcher (1976) found this mechanical method to be less efficient than dynamic methods for the collection of most groups of micro-arthropods from woodland sites. At times its efficiency proved to be less than that of an unheated Tullgren apparatus.

Some research workers have used a repellent chemical in place of the heat source. In 1934 Donohoe, Barnes and Fisher used chloropicrin to extract insects from grain products and decaying fruit. It does not appear to have been used again until 1965 when tested by Lauck. The extraction time was brief. Muchmore (1966) found the process valuable but showed that chloropicrin was too selective in use. His own study revolved around the collection of pseudoscorpions and he compared the chemical extractor with a heated Berlese funnel. Extraction was concluded after thirty-six hours. During this period he replaced the chloropicrin once.. His results showed that most specimens had left the soil during the first twelve hours of the chemical extraction process, whereas organisms left the soil throughout the thirty-six hour period in the heated funnel. In all he tested twenty-one samples. The Berlese apparatus was over three times as effective. In addition it appeared that chloropicrin damaged the specimens in such a way that it prevented them from leaving the soil. 'Soft bodied' species were less frequently obtained in the sample tubes than 'harder bodied' species. There was no significant difference between the two apparatuses when extracting spiders, insects, millipedes and centipedes. This suggests that this chemical might be used in remote areas where particular 'hard bodied' species are being sought. It could

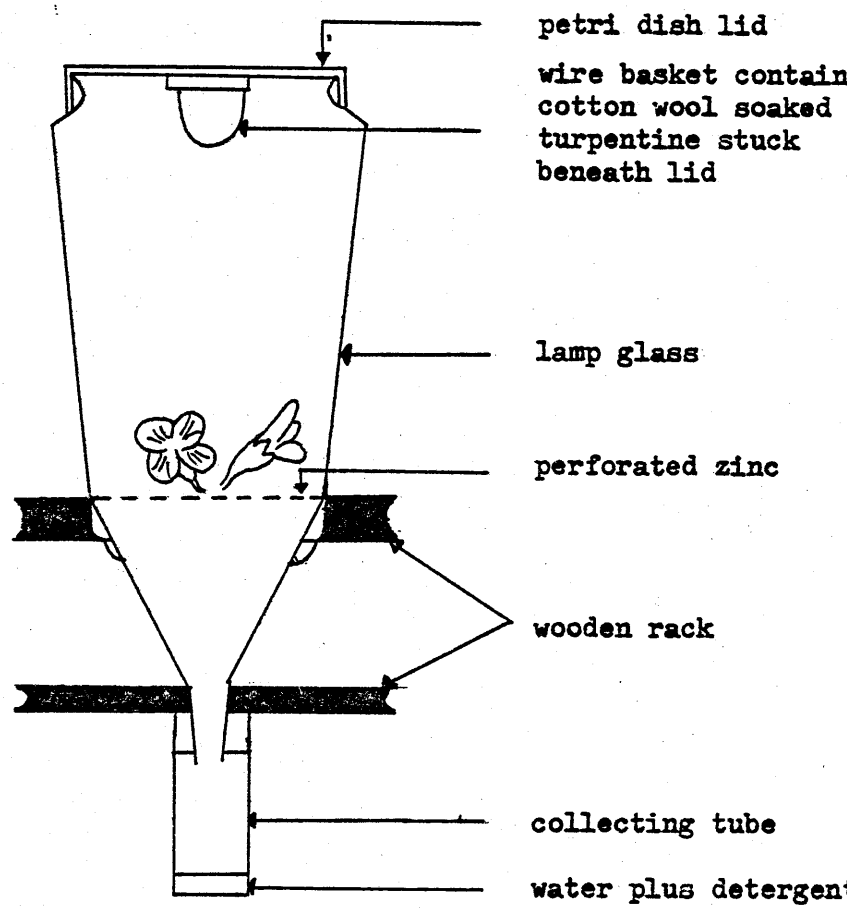
not be used in quantitative studies.

Macfadyen (1953) investigated the use of three chemicals in extraction funnels. These were: 'Gammexane' (benzene hexachloride), DMP (dimethyl phthalate) and DNOCHP (dinitro-ortho-cyclo-hexyl-phenol). All three proved to be promising for the collection of thrips and aphids but proved less efficient at extracting mites and collembolans. Brown (1973) used a dynamic funnel technique incorporating an aromatic hydrocarbon repellent in order to drive organisms from leaf litter. Naphthalene flakes were wrapped in cheesecloth and placed on top of the litter. His funnels were constructed from oilcloth and were designed for use in the field - hung from trees. Extraction was completed in 5-15 days. No results were listed and doubts relating to its efficiency cannot be discounted.

Turpentine was first used in a cylinder extraction process by Evans (1933) to repel thrips from flowers and blossoms. He found that adult thrips were successfully recovered from reasonably dry flower heads. It did not appear to extract immature stages efficiently. Lewis (1960) incorporated the use of turpentine into his funnel extraction unit. He fitted a plastic funnel to a lamp glass (Fig 12). The chemical was placed in cotton wool suspended beneath the tight fitting lid. Thrips left the sample within thirty minutes. Lewis confirmed that adult thrips of both sexes were successfully extracted. Lower numbers of immature stages were collected.

As a result of this literature search and because of the remoteness of the site at which I was to sample it was decided that the methods used in my study would be a chemical extraction process using turpentine as a chemical repellent and a dry Tullgren funnel technique. These were therefore first assessed by comparing results from litter samples collected from temperate oak woodland; the results are given in section 2.4.

Fig 12 - Lewis's Chemical Extraction Unit (after Lewis 1960)



Vertical Section

Results obtained in Amazonian Terra Firme rain forest and adjacent cultivated sites are described in sections 2.5 and 3.5.

2.3 Methods Used in This Study

2.3.0 Random Sampling Technique

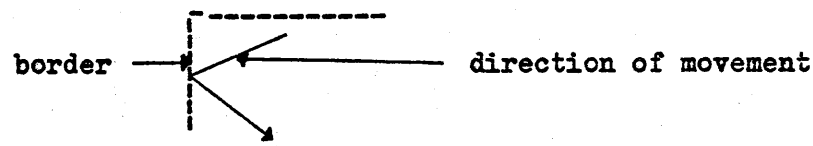
A random sampling technique was used to obtain sixteen cores from each of the two sites.

At each site an area in the shape of a square with sides of twenty metres was mapped out. This proved easy at the mandiocca site but was hindered at the rain forest site by the very large number of spindly tree trunks.

Initially at each site a starting point was selected at random.

A needle was spun and dropped to determine the direction of movement.

A random number table was used to decide how many steps to take in the direction indicated. A sample was then collected at the appointed spot. The direction of the next site was determined by re-spinning the needle at the previous sampling site. When the pacing reached the border of the site, the direction of movement turned back into the site as indicated:



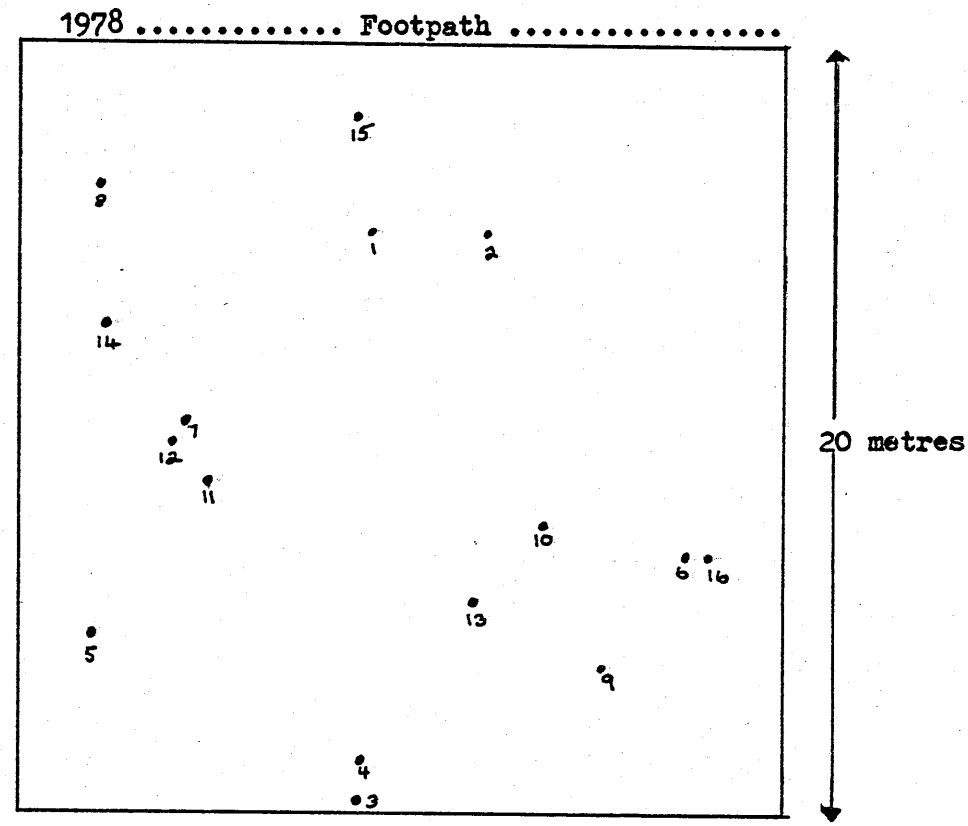
Care was taken at the rain forest site to step around all tree trunks but to continue in the chosen direction.

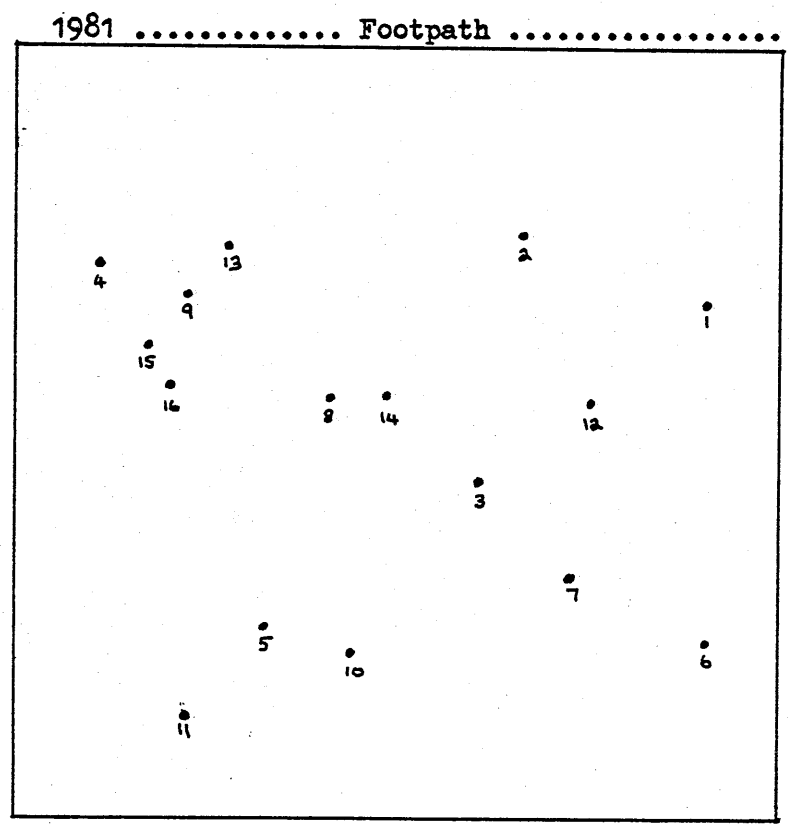
2.3.1 The Soil Corer

Many designs for corers have been described including those of Andrews and Broadfoot (1958), Macfadyen (1961), Dhillon and Gibson (1962), Tanton (1968), Vannier (1968), Fletcher (1976), Bieri (1978). Since the completion of this study other corer designs have been described by Pikul *et al* (1979) and Smith *et al* (1981).

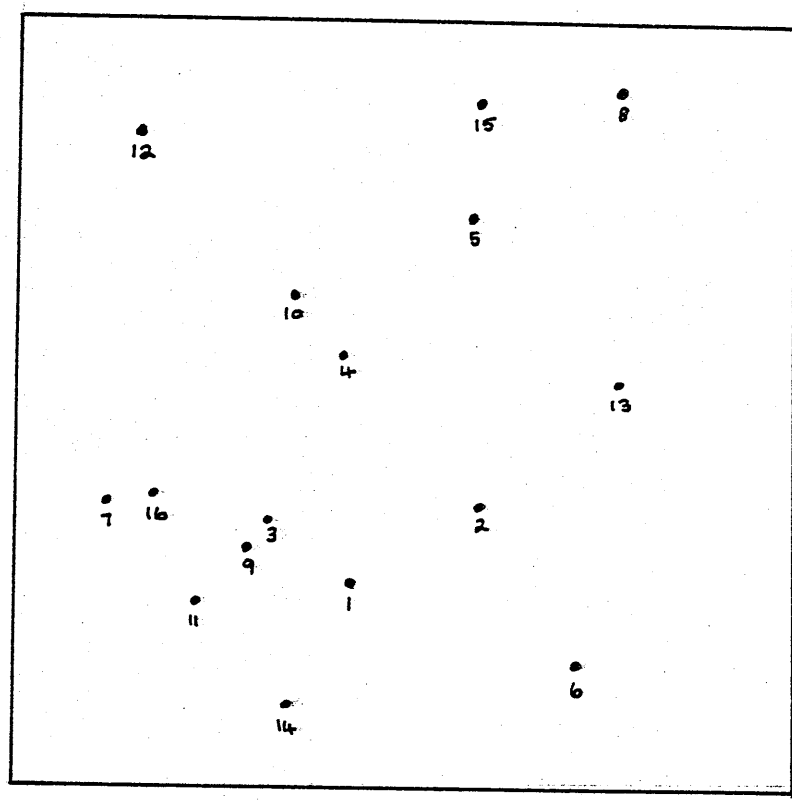
For this particular study in a remote isolated region a corer had to meet certain criteria; it had to be light and easily portable, yet at

Location of 16 Core Sites at Rain Forest (Site 2)





Location of 16 Core Sites at Mandiocca Field (Site 1)



Sample of Random Number Table

16	22	77	94	39	49
84	42	17	53	31	57
63	01	63	78	59	16
33	21	12	34	29	78
57	60	86	32	44	09
18	18	07	92	46	44

the same time tough enough to survive the rough handling it would receive at the hands of baggage handlers. Ideally it should be constructed in such a way that it could be dismantled for easier and safer transport. The corer also had to be built in such a way that samples would not be compressed. Finally the design had to be simple in order to facilitate on-site repairs.

Of the published descriptions the corer described by Fletcher (1976) almost fitted these criteria. This was based on a turf renovating tool and is illustrated in Fig. 13. In its original form it was too heavy and the ejector plate design too complex for my purposes. Thus it was modified in terms of materials and design. This 'improved' version (Figs. 14 and 15), consisted of a hardened steel cylinder (10cms internal diameter, 13cms long) with a sharpened cutting edge at one end (not serrated). This edge was easily re-sharpened using a file. To the opposite end a cross support of 3cms wide steel was welded. The ends were folded over the sides of the cylinder to increase its strength. A centrally sited hole was drilled into the middle of this steel strip (diameter 2cms). A hollow open-ended piece of steel tubing 5cms long having the same internal diameter as the drilled hole was welded into position above the hole. Two bolt holes opposite each other had previously been drilled into this steel tube. An outer alloy hollow rod 45cms long with an internal diameter of 1.5cm was fitted into the steel tube. Bolt holes parallel to those in the steel tube were then drilled. An alloy handle was welded to the top of this tube after a hole (diameter 1.5cm) had been drilled into it and it had been carefully aligned above the outer rod. A light alloy inner rod (75cms long) was fitted into the outer rod through the handle and checked for ease of movement. At the lower end two slots (10cms long) were cut parallel to the bolt positions in

Fig 13 - Corer after Fletcher (1976)

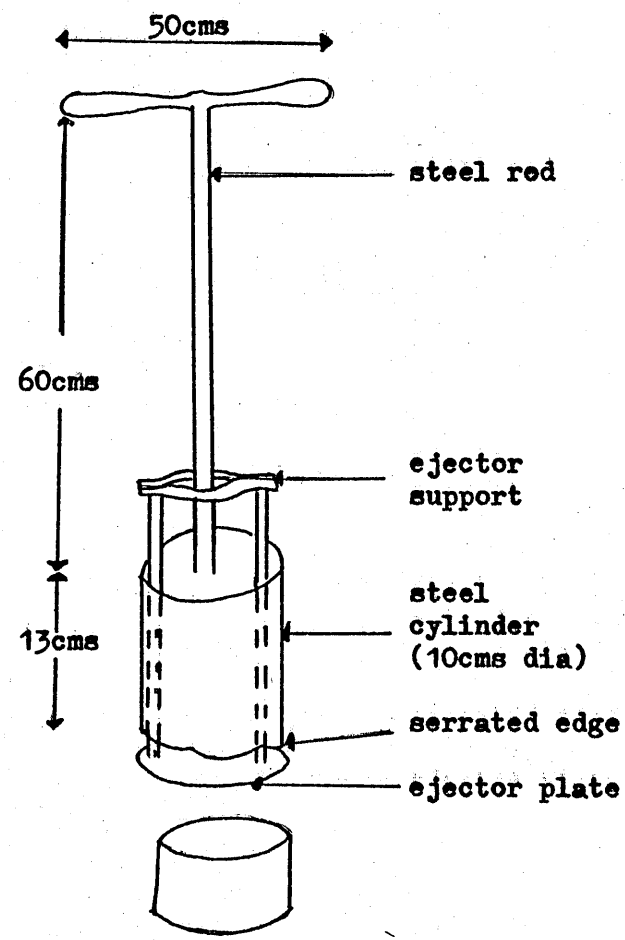


Fig 14 - Sortwell's Modified Corer

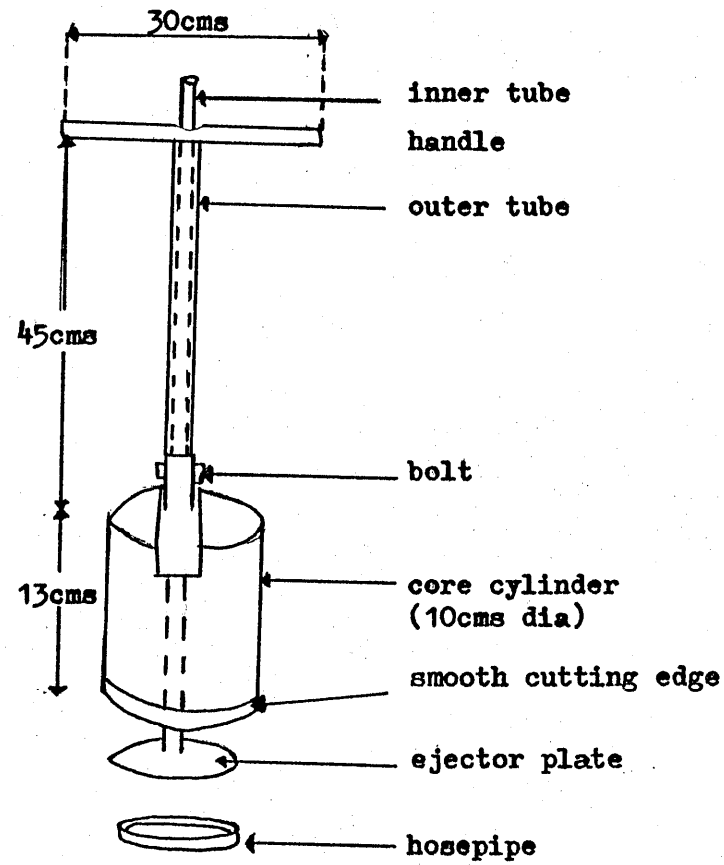
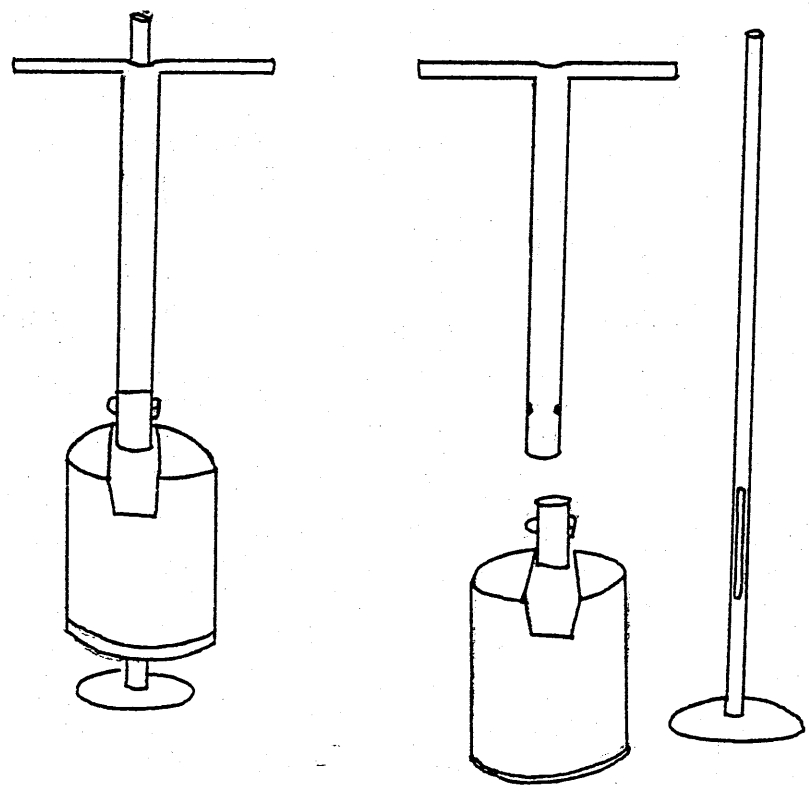


Fig 15 - Corer used in this Study



A Corer ready for use

B Corer unassembled into three parts for transport

Plate 1 - Soil Corer in use

Plate 2 - Test soil core (without litter)

order to allow the inner tube to move freely up and down the upper tube. In addition to the lower end an alloy circular plate with an internal diameter slightly less than the steel cylinder's internal diameter was welded. A single bolt retained the outer and inner tubes to the steel corer. Thus this model could be carried in three parts as hand baggage. Macfadyen (1961) criticised the use of corers fitted with ejectors on the grounds that samples were compressed during ejection. To counteract this a circular piece of 2cm diameter hosepiping tube was placed inside the corer in order to spread the downward pressure which was exerted on the pipe and not the sample. The additional advantage of having an ejector was that it could be set to a particular level in order to obtain samples of a required depth.

As a direct result of the problems encountered in importing equipment into Brazil and the difficulty in replacing the extractors, as well as the need to obtain sufficient samples to allow statistical analysis of the results it was decided to treat the litter, humus and upper soil to a depth of 5cms as a single unit. Plowman (1981) accepting that previous studies had done likewise proposed that faunal components of litter and soil should, in subtropical rain forest, be seen as occupying separate (although linked) environments. In 1978, as there was an equipment shortage, and following the experiences of earlier workers, it was felt to be valid to regard the zones as one unit.

Sample sites were located randomly. Prior to extracting core samples notes were made about the site and its location plotted on a grid. The cores were obtained in the following way: Large twigs were removed from the area. The cleaned corer (10cm internal diameter) with the ejector plate and pipe insert was set to the correct depth,

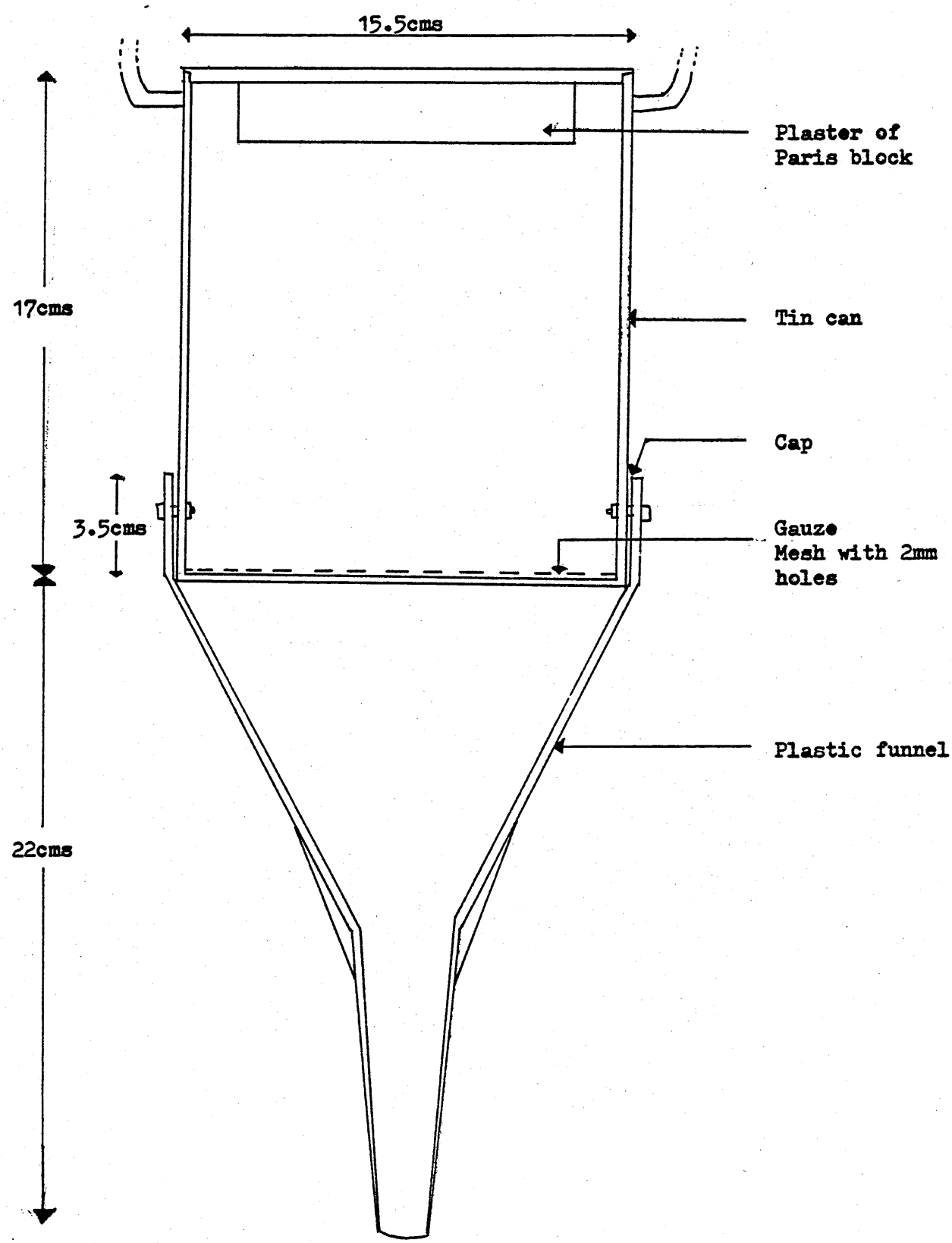
(5cm). The corer was placed in a vertical position above the site and gently pushed down into the ground with a slight rotation to the required depth indicated by a coloured line on the outside of the corer. The core was removed intact and undisturbed by twisting the corer prior to lifting it from the soil. Care was taken not to compress the sample when ejecting it. The core was carefully placed into a plastic bag for transport back to the campsite.

2.3.2 The Chemical Extraction Unit

Here, the cores were placed in an intact, but inverted position on the extractors. Two types of extractor were used. Soil animals from the first sixteen samples were extracted using the chemical extraction unit. These were constructed in Brazil according to the design tested in England. Unfortunately it was not possible to obtain metal funnels so a rigid plastic type was substituted. The design of this unit is similar to that of Lewis (1960) but has been improved and modified accordingly by the author (see Fig 12). His design consisted of a lamp glass fitted to a funnel. A wire basket was suspended beneath the lid and filled with cotton wool into which repellent chemical could be placed.

Glass equipment is not practical in remote regions so instead a tin can was used to replace the lamp glass (capacity 2.5L, diameter 15.5cms, length 17cms). Its base was removed by a tin opener. Luckily the cans which were available were supplied with a handle and tight fitting lid. The base of the tin fitted securely into the top of the rigid plastic funnel (internal diameter 15.5cms, length 22cms) and as the top of the funnel had a 3.5cms vertical wall this served as a support for the can and formed a ledge between the can and funnel base on which a perforated zinc gauze cut to size with 2mm pores sat (see Fig 16). The can was secured to the funnel by four small bolts in such a way

Fig 16 - Section Through Chemical Extraction Unit



that a small gap was left around the base to encourage air movement and to reduce condensation.

Gauze mesh was also used as a base and mould for plaster of paris which was set into the shape of a rectangular brick. This was stuck firmly to the lid. Turpentine immediately prior to extraction was dripped into the absorbent brick until it was saturated. After inverting the intact core into the extractor the lid was securely fitted into the top of the extraction unit. Organisms were extracted into 70% alcohol. This was completed in three days.

2.3.3 Tullgren Extraction Unit

The second set of sixteen samples in 1981 were collected in an identical way from the same undisturbed site. These were placed in an intact but inverted position on a small battery of Tullgren funnels. Each funnel was identical to those used in the chemical extraction unit and was fitted with the same size gauze mesh. These funnels were sited on a rack under the thatch of an open shed in a small clearing in the middle of the rain forest. Samples were allowed to dry out over seven days in the shade although at night when condensation was greatest a small paraffin lamp was suspended above the four funnels to provide heat. Thus some aspects of the techniques of Imadate and Kira (1964), Sheals and Hyatt (1964) and Bullock (1966) were incorporated.

2.3.4 Hand-sorting

A single square metre of litter and humus was collected in 1978 for hand-sorting. Each leaf, twig, etc being examined individually for organisms which were removed using a brush and preserved in 70% alcohol.

2.3.5 Sample Analysis

After extraction all the phials containing animals were completely

filled with 70% alcohol (industrial methylated spirits). These were tightly stoppered, sealed and packed for transport to England. After returning to England each phial was examined in turn. The contents being emptied into a petri dish engraved in its base with a grid of 1cm squares. Each empty phial was topped up with alcohol and washed into the petri dish to ensure that all specimens had been removed from it. Animals were counted and sorted using a binocular microscope illuminated from beneath. Specimens were removed from the petri dish to appropriately labelled tubes using a fine-haired brush. Each square of the grid was carefully examined for animals. Debris was turned over and teased apart with fine mounted needles to ensure that there were no 'escapes'.

2.4 Trial: Comparison of the Relative Efficiency of a New Portable Field Extraction Unit with a Dry Tullgren Technique using Soil Samples Collected from Temperate Woodland

2.4.0 Introduction

Sections 2.1 and 2.2 describe and compare the types of soil animal extractors available to research workers.

All techniques have limitations. Many of the dynamic extractors are too large for use in the field eg Macfadyen (1953, 1961) high gradient funnel and cylinder apparatus. All efficient laboratory dynamic extractors require a supply of electricity in order to provide light, heat and to power a thermo-element in Valpas's (1969) apparatus. Most of the mechanical extractors are too bulky and involve the transport of such chemicals as xylene and magnesium sulphate. In isolated regions with difficult access routes weight restrictions apply. In Brazil, licences are needed to import and transport certain chemicals. Further, Macfadyen (1953) reported that analysis of the Salt and Hollick (1944) wet sieving and

flotation technique took twenty-four man-hours to complete. This was up to ten times as long as a dynamic Tullgren technique required. Other workers have been faced with similar problems when working in remote regions and hence have designed and tested portable extractors, these are discussed in section 2.2. Salmon's (1946) portable unit needs a supply of methylated spirits to heat a water bath incorporated into a Tullgren funnel. This chemical is not available at the site of the main study in Brazil. The chemical is not permitted aboard aircraft and it would be too difficult to arrange transport by hired boat. Macfadyen (1953) described an expedition extractor which in practical terms is much too bulky to transport through the rain forest. In addition, paraffin provides the power to heat the unit and this is in very short supply in Amazonia. Belfield (1976) adapted the Aucamp and Rykes (1964) grease film extractor for use in the field. This was not suitable for several reasons; firstly it damaged specimens and secondly, it was too large to transport easily and finally, petrol or other solvents are necessary to wash the grease plates into collecting phials. This again is not available at the study sites.

Tullgren style analysis also has difficulties, Evans, Browning and Hyatt used a collapsible polythene funnel (Fig 8) which is suspended in trees. Unfortunately this has a tendency to swing in the wind disturbing the sample which results in considerable amounts of debris accumulating in the collecting phials. Hyatt (in a personal communication 1978) suggested the use of standard plastic funnels fitted with 2mm gauze. Imadate and Kira (1964) and Bullock (1966) both used simple plastic funnel techniques at tropical sites. The former allowed his samples to dry in the sun whilst Bullock preferred a slower drying period in shade. Bullock (1967) felt that this

technique offered the only feasible method of collecting samples in the field. Thus it was decided to use dry funnels of this sort in Amazonia.

Bullock (1967) suggested that the use of chemical repellents might offer a possible alternative to Tullgren techniques. Donohoe et al (1934), Lauck (1965) and Muchmore (1966) used chloropicrin as a repellent. It was found to be too selective, and Muchmore found a Berlese funnel to be three times more effective. Macfadyen (1953) found the results disappointing when he tested 'Gammexane', DMP and DNOCHP as repellents. None proved suitable. Brown (1973) experimented with Naphthalene as a repellent but his lack of published results cast doubts on its suitability. In a personal communication Mound (1977) suggested turpentine as a repellent. Evans (1933) and Lewis (1960) did use turpentine to extract thrips from flower heads and their results were successful. A chemical extraction unit seemed to be ideal for Amazonian rain forest and it was decided to test a unit using turpentine as a repellent. It was planned that its relative efficiency should be compared with the results obtained using a dry Tullgren funnel in England before the expedition's departure.

2.4.1 Method

Soil samples were collected from temperate oak woodland (growing on the slopes of Blorenge near Abergavenny, South Wales) using the corer and technique described in section 2.3.1.

Ten soil cores were taken (10cm diameter, 5cm deep) for laboratory extraction. Five samples were placed in chemical extractors, and five in dry Tullgren funnels heated from above by a low wattage bulb (40 watt). The construction and extraction procedure for these two extractors is described in sections 2.3.2 and 2.3.3. Extraction

was completed by the sixth day. The collecting phials were examined and the animals sorted as described in section 2.3.5.

2.4.2 Results

Table 1 - Comparison of the Mean Numbers of Soil Animals Collected for Five Core Samples Subjected to Chemical and Tullgren Funnel Extraction

	Extraction Technique	
Animal Group	Chemical	Tullgren
Acari	46.2	40.4
Collembola	30.6	26.6
Myriapoda	1	2
Other Insects	19.4	22
Araneae	0.6	0.2
Nematoda	0.8	1.4
Total	98.6	92.6

2.4.3 Discussion

Insufficient samples were collected for statistical analysis and the animals were only rough-sorted to the Order level. Nevertheless the results suggest that there is little difference in the efficiency between the two types of extractor. The chemical unit extracted more Acari, Collembola and Araneae whilst the Tullgren funnel extracted more Insects, Myriapods and Nematodes. However the differences are not sufficiently different to demonstrate the unsuitability of either technique.

It was therefore decided on the basis of this trial to use both techniques in tropical conditions and to determine the most efficient

technique in the field. In addition a hand-sorting method of analysis would be used to provide a basis for additional comparisons.

2.5 Comparison of the Relative Efficiency of a New Portable Extraction Unit for Use in the Field with a Tullgren Funnel in a Tropical Environment

2.5.0 Introduction

This study was undertaken in Terra firme rain forest in the Amazon basin. The site has been described in section 3.1 and is referred to as Site 2. This study was through necessity undertaken in two phases. During the first expedition to the site in 1978 problems were encountered with Brazilian customs officials who at the last moment refused permission for the importation of expedition equipment. As a result none of the soil sampling equipment that had been prepared in England was available for use in the field. Fortunately sufficient scrap material was available to construct two chemical extraction units; the soil corer had travelled with the author. At the second visit in 1981 to the same area, which continued to remain undisturbed by man, the same soil corer was used to obtain the same number of samples which were then extracted in a Tullgren funnel. On both occasions samples were obtained throughout the last two weeks of July and throughout August. Whenever a new type of extraction unit is constructed, or an existing piece of equipment is modified it is essential to have some measure of its efficiency in order to provide reliable data relating to population dynamics. Then phenology of soil arthropods depends upon the use of an extractor with a high degree of efficiency (Goddard 1979). Many different techniques for estimating the efficiency of an extractor have been used. Some workers prefer to introduce marked individuals to sterile soil samples eg Aucamp and

Ryke (1963). Belfield using a modified version of this grease film extractor obtained 100% recovery for a variety of micro-arthropods. Goddard (1979) using ten marked pseudoscorpions achieved a 70% recovery rate and therefore efficiency level for her modified Tullgren apparatus. With such a low number of test individuals the reliability of this technique is to be doubted - particularly as far as a dynamic means is concerned because of the fundamental principles upon which the technique relies (Murphy 1962). Gabbutt (1959) and Kempson et al (1963) have made known introductions to sterile soil and pointed out that the nature of the soil is changed by its sterilisation. Thus this technique is more valid for mechanical methods which do not rely upon the behaviour of the fauna, when fauna both dead and alive will be extracted.

Other workers have compared an extraction technique with a hand-sorting method eg Forsslund (1953). Macfadyen (1953) pointed out that this means of direct counting is very time consuming and inaccurate. As a result more recently soil zoologists have compared the efficiency of one extractor against another extractor of a different type and to ignore hand-sorting. Frequently extractors have been compared with a Tullgren apparatus. Such comparisons have been undertaken by Macfadyen (1953, 1961), Muchmore (1966), Kikuzawa et al (1966), Marshall (1972), Huhta (1972), Fletcher (1976), Petersen (1978). This technique gives an indication of the general efficiency of a particular technique but there is a danger that a worker will encounter difficulties in making a valid comparison (Bullock 1967).

Further one must remember that no one apparatus will be one hundred percent efficient for every group of soil animals (Macfadyen 1961). Thus with limitless resources and a large laboratory the only

effective method of ensuring accurate population estimates would be to use appropriate methods for each group of animals.

Within the tropics a variety of extraction techniques have been used. These have already been listed in section 2.1, but two types of technique are commonly used: flotation and a Berlese-Tullgren technique. The variety of techniques adds to the problem of comparing results from different areas. Macfadyen (1962) proposed that for community studies only, the precision of techniques should be comparative (Bullock 1967). Further one must remember that every extraction technique is likely to be most efficient in the hands of its creator (Kuhnelt 1961).

The inaccessibility of remote sampling sites to a large extent determines the techniques that will be used. The storage of samples prior to extraction has already been discussed in section 2.1.1. Imadate and Kira (1964), Bullock (1966) and Sheals and Hyatt (1964) have all extracted samples on site, a technique also undertaken by the author for this study. Sheals and Hyatt (1964) collected samples at a distance of several miles and used Tullgren funnels heated by portable lamps. Imadate and Kira (1964) preferred to use direct sunlight to dry the samples whilst Bullock preferred a slower drying technique in the shade.

Bullock (1967) suggested that repellent chemicals offered a possible alternative means of extraction but since that time few studies into this field have been made. Thus, it was felt important to test and compare a new chemical extractor made available to me by modifying Lewis's apparatus (1960) with a dry Tullgren technique. Trials in this country in 1977 proved promising. There was no significant difference in the extraction efficiency between the chemical unit and a heated Tullgren funnel. However the chemical unit had been designed

specifically for use on site in a tropical climate and so this experiment was carried out to determine its efficiency there.

2.5.1 Method

An identical sampling procedure was followed in 1978 and 1981. The sample site in both years was almost identical. In both years sixteen soil cores were taken using the corer and technique described in section 2.3.1. In 1978 two chemical extraction units using turpentine as a repellent were used to collect soil animals whereas in 1981 dry Tullgren funnels were used (sections 2.3.2, 2.3.3). Animals were preserved in alcohol for analysis in England as described in section 2.3.5.

2.5.2 Changes at the Site between 1978 and 1981

The very same area of rain forest was used on both occasions. This had apparently remained undisturbed by man. The relative humidity ranged from 83-95% and the soil's acidity ranged between pH 4-6. The weather followed a similar pattern with rain falling on average every other day for one to one and a half hours in the late morning or early afternoon.

The same hut was used as the base for extraction. This was thatched and had no sidewalls.

It was necessary to undertake the study in two stages as at the point of entry in 1978 the Brazilian authorities refused permission for the importation of expedition equipment. It was possible however to build two chemical extractors from scrap. This limited the amount of work which could be accomplished. In 1981 a battery of Tullgren funnels were carried to the site. It has therefore been possible to assess the relative efficiency of the two extraction techniques on different occasions. On the first visit in 1978 comparisons were made between the soil animals living in cultivated soil and rain

forest soil. During the second visit (1981), efforts were concentrated on the extraction of soil animals using a dry Tullgren funnel technique.

2.5.3 Results

The data from the comparison of the dry Tullgren funnel and the chemical extraction unit at a rain forest site are summarised in Fig. 17 and Tables 2-5.

In order to statistically analyse the differences between the two techniques all data was transformed to Log(n+1), a technique used by Fletcher (1976) as part of the International Biological Programme in order to allow for the fact that the fauna is not randomly distributed in the soil. The results were then 'T' tested in accordance with Fletcher (1976) and Lasebikan (1975).

Table 2 shows that the Tullgren technique is, in relative terms of total numbers extracted, far more efficient (twenty-six times) than the chemical extraction unit. It extracted the highest mean numbers of soil and litter animals for all groups except the Lepidoptera, Lumbricidae, Nematoda and Enychtraeidae.

Table 3 (and Fig 17) show the percentage composition of the rain forest floor fauna using the two types of extractor. In relative terms the proportion of Collembola extracted by the chemical unit was greater than that of the Tullgren funnel. Further in percentage terms the former collected more arthropods (other than Acari and Collembola) and non-arthropod fauna than the Tullgren funnel did. The Tullgren unit extracted far more Acari than the chemical unit. The former unit's results suggesting that Acari made up 82.2% of the floor fauna whilst the chemical unit achieved a figure of 19.72%.

Table 4 gives the mean numbers of soil animals per square metre for each of the three extraction techniques. This quite clearly demonstrates

Table 2 - To Determine the Efficiency of a Tullgren Funnel Extractor Compared with a Chemical Extraction Unit Using Samples From the Rain Forest Floor (0.5cm deep)

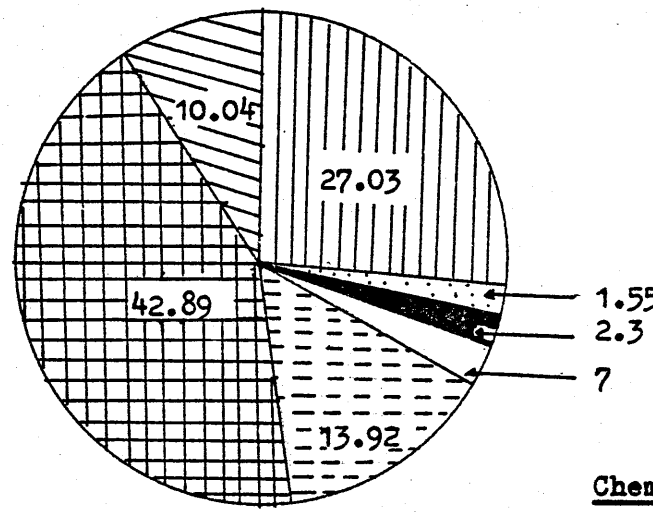
Sample Size : 10cms diameter x 5cms deep

Method / Animal Group	Arithmetic Means of 16 samples		Transformed Means = LOG(n+1)			't' Test	Level of Significance	More efficient Technique
Arthropoda	Tullgren	Chemical	Tullgren	Chemical	S.E.			
							%	
Arachnida								
Pseudoscorpiones	0.875	0.125	0.213	0.038	0.06373	2.7459	2	T
Araneae	2.06	0.125	0.437	0.038	0.06420	6.2149	0.1	T
Acari								
Prostigmata	26.875	0.25	1.430	0.067	0.06955	19.597	0.1	T
Gamasina	18.75	0.125	1.275	0.038	0.04323	28.614	0.1	T
Rhodacaridae	35.25	0.125	1.503	0.038	0.0684821	21.392	0.1	T
Uropodina	6.125	0.062	0.828	0.019	0.04237	19.093	0.1	T
Astigmata	8.937	0.375	0.966	0.105	0.05789	14.8730	0.1	T
Cryptostigmata	259.34	2.25	2.335	0.383	0.09843	19.831	0.1	T
Collembola								
Onychiuridae	4	0.187	0.690	0.057	0.03748	16.889007	0.1	T
Poduridae	6.125	0.875	0.818	0.218	0.07275	8.2474	0.1	T
Isotomidae	14.937	0.812	1.183	0.202	0.06565	14.9428	0.1	T
Entomobryidae	6.18	1.87	0.813	0.323	0.09669	5.0677	0.1	T
Sminthuridae	2.937	0.625	0.569	0.143	0.06737	6.3232	0.1	T
Other Insects								
Diplura	1.125	-	0.249	-	0.06723	3.7037	0.1	T
Thysanura	-	-	-	-	-	-	-	-
Diptera	1.875	1	0.357	0.213	0.10367	1.3890	-	-
Coleoptera	7.687	1.56	0.885	0.328	0.09084	6.1316	0.1	T
Lepidoptera	-	0.25	-	0.043	0.04362	-0.985	-	-
Thysanoptera	1.125	-	0.273	-	0.05590	4.8837	0.1	T
Hemiptera	8.75	0.625	0.959	0.143	0.07384	11.05092	0.1	T
Psocoptera	-	-	-	-	-	-	-	-
Hymenoptera	11.125	2.125	1.052	0.348	0.08935	7.8791	0.1	T
Orthoptera	0.187	-	0.038	-	0.03762	1.010	-	-
Isoptera	1.812	0.687	0.324	0.161	0.10460	1.5583	-	-
Myriapoda								
Chilopoda	0.25	-	0.564	-	0.04092	13.7829	0.1	T
Diplopoda	0.625	0.312	0.173	0.086	0.06136	1.4178	-	-
Pauropoda	1.687	0.062	0.392	0.019	0.05456	6.8365	0.1	T
Symphyla	1.062	0.062	0.273	0.019	0.05443	4.6665	0.1	T
Other Animal Groups								
Platyhelminthes	-	-	-	-	-	-	-	-
Nematoda	0.312	0.062	0.049	0.038	0.05499	0.9456	-	-
Enchytraeidae	0.312	1.125	0.094	0.258	0.07090	2.313	5	C
Lumbricidae	0.937	0.312	0.259	0.062	0.05371	3.6678	0.1	T
Isopoda	0.937	0.125	0.185	0.019	0.07219	2.299	5	T
Gastropoda	-	-	-	-	-	-	-	-

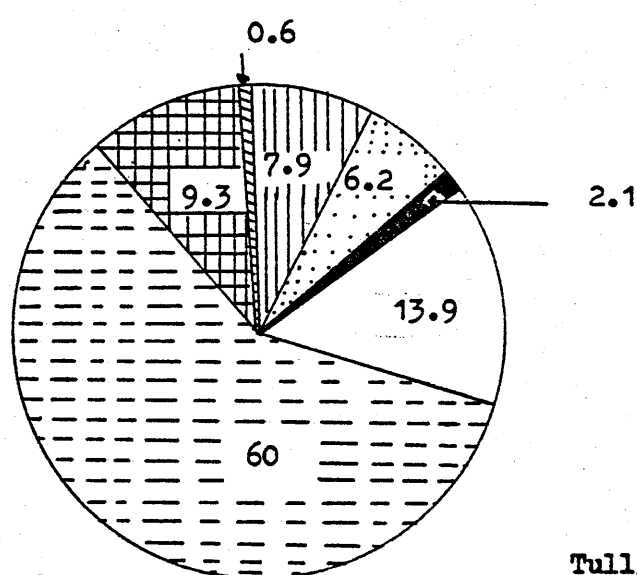
Table 3 - The Percentage Occurrence of Rain Forest Floor Fauna in the top 5cm as Calculated using Two Different Extraction Techniques

	% Occurrence Following Extraction Techniques	
Major Group	Tullgren	Chemical
Collembola	7.9	27.03
Prostigmata	6.2	1.55
Astigmata	2.1	2.32
Mesostigmata	13.9	1.93
Cryptostigmata	60.0	13.92
Other Arthropods	9.3	42.89
Other Groups	0.6	10.04

Fig 17 - Percentage Composition of Rain Forest Floor Fauna in Top 5cm in this Study



Chemical Unit Sample



Tullgren Sample

- Collembola
- Prostigmata
- Astigmata
- Mesostigmata
- Cryptostigmata
- Other arthropods
- Other fauna

Table 4 - Estimates of the Mean Numbers of Soil Animals Per Square Metre Following Tullgren and Chemical Extraction and Hand-sorting

Animal Group	Extraction Technique		
	Tullgren	Chemical	Hand-sorting
Acarina	45,226.8	405.70	101
Collembola	4,351.0	556.20	2
Isopoda	119.3	15.90	1
Pseudoscorpiones	111.4	15.90	4
Other Arachnida	262.2	15.90	3
Diplopoda	79.6	39.70	3
Other Myriapoda	381.8	15.80	1
Diplura	143.2	0	0
Coleoptera, Diptera larvae	405.8	127.30	16
Coleoptera	707.8	127.30	0
Isoptera	230.7	87.40	25
Formicidae	1,416.2	270.50	288
Total	53,435.8	1,693.50	444

Table 5 - Comparison of the Numbers of Species of Acarina and Collembola Collected with a Chemical Extractor and Tullgren Funnel

Animal Group	Extraction Technique	
	Chemical	Tullgren
Prostigmata	4	12
Mesostigmata		
Gamasina	3	16
Rhodacaridae	3	3
Uropodina	3	5
Astigmata	4	8
Cryptostigmata	19	40
Total Acarina	36	84
Onychiuridae	2	4
Poduridae	4	6
Isotomidae	8	6
Entomobryidae	8	12
Sminthuridae	1	3
Total Collembola	23	31

the superiority of the Tullgren technique which collected significantly more specimens for all the main animal groups listed giving a total mean number of 53,435.8 specimens per square metre compared to 1,693.5 specimens calculated for the chemical extraction unit and only 444 for the hand-sorting technique.

In addition to studying the number of specimens extracted by the Tullgren and chemical extractors it is worth looking at the number of different species collected by each apparatus. Table 5 shows that the Tullgren technique extracted eighty-four species of Acari and thirty-one species of Collembola, whereas the chemical extractor using turpentine as a repellent collected thirty-six species of Acari and twenty-three species of Collembola. This does suggest a possible use for the chemical extractor as a means of rapidly collecting a large number of species in a short space of time, eg when samples are being collected by members of mobile expeditions.

2.5.4 Discussion

A modified version of Lewis's extraction unit (1960) for collecting fauna from flower heads is described and its efficiency compared with a dry Tullgren technique. Some comparisons with a hand-sorting technique were also made. The result for the two extractors is shown in Table 2. This indicates a large difference in the efficiency of the two techniques when sampling the rain forest floor (Terra firme type).

Many previous workers including Macfadyen (1961) and Fletcher (1976) have shown that several small samples are better than one large sample. The variation in numbers collected per sample can be attributed to at least two factors: Debauch (1962), Healy (1962), Hughes (1962) and Fletcher (1976) have produced evidence to show that soil arthropods tend to be clumped together in the soil. This

observation was also made in this study. It was very noticeable that several species of Acari were present in one or two samples in very large numbers and totally absent from many others. Secondly the forest floor contains a great number of microhabitats. Aoki (1967) distinguished fifteen in the forest floor at Minso, Japan. These included freshly fallen leaves of the different species of dominant trees, the surfaces of boulders, fallen twigs and trunks, moss covering the base of plant stems, the different layers of the soil, etc. In this study microhabitats were not distinguished between and perhaps should have been.

One obvious source of error in the comparison of the chemical extraction unit and the Tullgren funnel is that data was collected on different occasions but there did not seem to be any significant changes in the biotic and abiotic factors which had remained stable and unaffected by man. Sampling took place at the same stage of the year - at the end of the rainy season and the beginning of the dry season, and over exactly the same time period. It was fortunate that the weather followed a similar pattern in the two sampling seasons. The time of collection was selected in order to sample the fauna at a time when the population was expected to be at its height (Loots and Ryke 1966, Lasebikan 1974, Leow 1974, Guphta and Mukharjii 1978, Plowman 1981, Vallejo 1981).

The results illustrated in Table 2 indicate clearly that if the chemical unit had been the only type of extractor used the author would seriously have underestimated the population of soil-dwelling fauna in tropical rain forest. However the Tullgren technique was not 100% efficient. Indeed it is unlikely that any one technique will be be 100% efficient for all the animal groups present in the sample (Macfadyen 1953). This field Tullgren would have been more

efficient had a controllable heat source been available. Thus its efficiency was estimated to be between 60-70% of normal on this basis. Another shortcoming was that a 2mm gauge gauze (Reca and Rapoport 1975) was used. When compared to the Tullgren unit the chemical unit was more efficient at recovering Enchytraeidae only. Data in Table 4 shows however that it was far more efficient than the hand-sorting method for all groups except the Formicidae which were easily seen and collected by hand-sorting.

The chemical extraction unit's efficiency was also better than hand-sorting as demonstrated in Table 4, and it was more efficient than the Tullgren funnel when collecting Enchytraeidae. The chemical extraction unit was particularly inefficient at extracting micro-arthropods, particularly in contrast to temperate woodland. The trials reported in section 2.4 show that the chemical unit was as efficient as the Tullgren funnel for the majority of fauna groups in these habitats. The poor performance of the chemical unit may be a result of 1) the considerable variation in environmental factors in the tropics. The average air temperature at the time of extraction was 25°C. Within the metal chemical unit this temperature could have caused the turpentine to evaporate rapidly, these vapours would then escape through the lid at a faster rate. Although tight-fitting, the lid did not have a rubber seal. It would be beneficial to incorporate a seal in future designs. 2) The relatively higher temperature and high external air humidity (Seadstedt and Crossley 1979) could have caused condensation problems within the funnel trapping animals that would have otherwise been collected. This problem has been highlighted by Harlov (1947) and Macfadyen (1961). It is difficult to see how these difficulties can be overcome when working in the field. A possible solution would be to drill minute holes in the lid and to site the chemical holder lower down the sample

chamber against the wall. If the collecting phial was not attached to the base of the funnel and small holes with flanged edges were drilled through the top of the funnel horizontally into the sample chamber, air circulation might improve and reduce some of the condensation. The sides of the funnels should have been washed by alcohol into the phial. 3) One must however bear in mind the other effect the high air humidity in the immediate vicinity of tropical rain forest had. This averaged over ninety percent during daylight hours, and the moisture-filled air may well have hindered the distribution of turpentine vapours. 4) A more significant factor could have been the moisture content of the sample. The rain forest samples were considerably damper than those from temperate woodland. It was impossible in this remote site to calculate the percentage of moisture in each sample although in comparison with England, and the disturbed mandiocca site, it was wet. Previous soil moisture studies in the tropics suggest that soil moisture level can vary between nine percent and thirty percent (Olivier and Rykes 1966, Loots and Ryke 1966, Singh and Pillai 1975). It is well known that soil moisture is a major factor effecting the distribution of micro-arthropods. It may well be that when using a chemical repellent such as turpentine, high soil moisture levels may inhibit the penetration of the turpentine vapour into the sample through airspaces which are saturated with moisture. However, the opposite view could be taken that is that the effect of the turpentine vapours was to kill the animals before they had an opportunity to migrate through the sample. More precise experiments would be desirable.

It is unlikely that sample compression could have influenced the results as the same corer was used for both extraction techniques. In the same way 70% alcohol was used as the collecting fluid for both

extractors and is unlikely to have influenced the results (Fletcher 1977).

The data presented in Tables 2 and 4 indicates that the chemical extraction unit is of no quantitative value when studying population size in tropical rain forest soils. Nevertheless it has its virtues for the length of extraction time is short and samples can be taken and extracted rapidly by mobile expeditions remaining at a station for only twenty-four hours. Other techniques require far more time. The unit has been shown to extract a considerable number of Acarine and Collembolan species (Table 5) and could be used to sample for new species of these groups. For instance using this apparatus I have collected the first known Pauropods from South America (personal communication from Dr U Scheller, Sweden). Without doubt the chemical extraction unit would be a more efficient and better alternative to hand-sorting - a tedious process taking up to twenty-four man-hours per sample. Hand-sorting encourages the escape of the more active fauna and the inevitable missing of smaller micro-arthropods. Another advantage of the chemical unit is that it is not necessary to store the sacks of litter and soil required for hand-sorting.

From Table 4 one can see that by using the chemical extraction unit estimates of the population per square metre to be about 1,693.5 individuals. This figure is low when compared to other tropical population estimates, for instance by Lasebikan (1972) obtained a count of 4,500 Acari in a Nigerian rain forest using a Burkard Berlese-Tullgren funnel. Subsequently he found the Macfadyen high gradient canister apparatus to be more efficient obtaining a count of 24,000 Acari. When compared to Beebe's hand-sorting results the chemical unit is three times more efficient. The hand-sorting

technique of this study yielded a population count of 444 individuals per square metre, surprisingly close to the figures of 407 of Goodnight and Goodnight (1956) and 500 of Beebe (1916) but lower than the 700 counted by Dammerman (1925, 1937) in the East Indies. Even taking into account the estimated 50% losses of Beebe the resulting figure of 1,000 individuals per square metre is very low when compared to the Tullgren results of this study which suggests a population size of 53,435.8 individuals per square metre.

The population estimate obtained with the Tullgren funnel compares well with Beck's figure of 87,150 per square metre shown in Table 6. These results were obtained in 1970 and 1971 whilst working in a nature reserve in Amazonas within easy reach of a laboratory in which soil fauna were collected using a Berlese-Tullgren technique. Although the difference in population size is 33,614, it can be explained in terms of extraction efficiency and the differences in the two sites. Using a laboratory-based extraction Beck was able to control the heat of the sample reducing the possibility of a too rapid drying out of the sample which traps animals. If a correction factor based on Reca and Rapoport's study (1975) is incorporated into this study's results in order to take into account the gauze mesh size a population estimate of 69,468 per square metre is obtained. This would give an extraction efficiency in the order of 79.7%. Escapes, insufficient control of temperature and humidity gradients as well as the sites being one thousand miles apart account for the 20.29% difference. Although both sets of samples were obtained from Terra firme rain forest there are significant differences between the two sites. Within the reserve sampled by Beck there were more emergent trees and less Cecropria spp. This would effect the type of litter ie fallen leaf sizes and possibly also the pH of the soil

Table 6 - Comparison of Site 2 with a Similar Terra Firme Rain Forest Site Examined by Beck (1970, 1971)

All results expressed as 10^6 individuals per hectare.

Animal Group	Site 2	Beck's results
Acarina	452.27	727
Collembola	43.50	119.8
Isopoda	1.19	0.7
Pseudoscorpiones	1.13	2.1
Other Arachnida	2.62	0.7
Diplopoda	0.80	2.8
Other Myriapoda	3.82	3.5
Diplura	1.43	1.4
Coleoptera, Diptera larvae	4.06	4.0
Coleoptera	7.08	1.4
Isoptera	2.31	0.9
Formicidae	14.16	7.2
Total	534.37	871.5

which would affect the distribution of some species of soil animals. Thus an estimate of 53,435.8 animals per square metre is encouraging especially when compared with population estimates obtained by other workers in the tropics. Williams in Panama (1941) using a similar dynamic method calculated that there was an average population of 9,822 per square metre in rain forest. Van Der Drift (1968) only obtained population estimates of between 3-4,500 per square metre using a Tullgren funnel. Singh and Pillai (1975) collected soil fauna from several types of tropical soil estimating populations to be from 9,000 to 20,000 animals per square metre whilst Singh and Mukharjii (1973) reported a population of 16.87 thousand animals per square metre. Lasebikan (1974) reported a population in excess of 24,000 Acarines per square metre in Nigerian rain forest.

Tables 3 and 7 illustrate the percentage representation of each soil animal group. These show that Acarines were the dominant group of soil animals (when using the Tullgren funnel) with Collembola forming the second largest group. The Acarines constituted 82.15% whilst Collembola formed 7.9%. Using the chemical extraction unit, 27% of the population was Collembola. The difference between these results can be explained on the one hand by the fact that Collembola could escape from the Tullgren funnel and on the other that the chemical unit was inefficient at extracting other groups of animals, suggesting that the Collembola formed a larger percentage of the fauna than they in fact did.

Williams (1941) using a Berlese funnel in rain forests in Panama found the dominant group to be Collembola (36.8%) followed by Acarina which were the second commonest group (24%) as seen from Table 7. This seems to be the exception as most other workers in the tropics have demonstrated that Acari form the dominant group of

Table 7 - Individual Animal Groups: Mean Percentage of Occurrence in the Total Population of Rain Forest Soil Compared With the Results of Williams' Investigations in Panama 1941

Animal Group	Extraction Technique		
Arthropoda	Tullgren	Chemical	Williams Berlese/ Tullgren
Arachnida			
Pseudoscorpiones	0.2	0.77	No data
Araneae	0.47	0.77	0.10
Acari			
Prostigmata	6.21	1.54)	
Gamasina	4.33	0.77)	
Rhodacaridae	8.14	0.77)	24.00
Uropodina	1.41	0.38)	
Astigmata	2.06	2.32)	
Cryptostigmata	60.00	13.92)	
Collembola			
Onychiuridae	0.92	1.156)	
Poduridae	1.41	5.413)	
Isotomidae	3.45	5.02)	36.80
Entomobryidae	1.42	11.56)	
Sminthuridae	0.67	3.86)	
Other Insects			
Diplura	0.26	-	No data
Thysanura	-	-	No data
Diptera	0.43	6.18	0.45
Coleoptera	1.77	9.65	1.19
Lepidoptera	-	1.54	No data
Thysanoptera	0.26	-	No data
Hemiptera	2.02	3.86	0.31
Hymenoptera	2.57	13.14	27.44
Orthoptera	0.04	-	0.20
Isoptera	0.41	4.25	No data
Myriapoda			
Chilopoda	0.05	-	0.17
Diplopoda	0.14	1.93	1.19
Pauropoda	0.39	0.38	0.96
Symphyla	0.24	0.38	0.21
Other Animal Groups			
Platyhelminthes	-	-	0.04
Nematoda	0.07	0.38	0.08
Enchytraeidae	0.07	6.96	No data
Lumbricidae	0.21	1.93	0.93
Isopoda	0.21	0.77	1.67
Gastropoda	-	-	0.40

fauna followed by Collembola (Beebe 1916, Strickland 1947, Van Der Drift 1968, Beck 1970 and 1971, Singh and Mukharjii 1973, Singh and Pillai 1975, Singh and Singh 1975). The results of this study using the Tullgren funnel (the only acceptable extractor) support the observations of these workers showing that Acari constituted 82.15%, whereas Collembola were only 7.87% of the soil animal population.

The Tullgren funnel proved to be a satisfactory simple technique for use in remote regions devoid of walled huts that could be used as makeshift laboratories. Little in the way of materials and chemicals needed to be purchased or transported and a wide range of species was extracted, particularly Acari. From Table 3 and Fig 17 it can be seen that amongst the Acari the Cryptostigmatid mites were present in the largest numbers forming 60% of the total population whilst Mesostigmatid mites formed 13.9% of the population. Singh and Pillai (1975) found that in fields prostigmatid mites were the dominant group of Acari whilst Cryptostigmatids were more dominant in sites with greater depths of humus. This was also reported by Loots and Ryke (1967) who found Cryptostigmatid mites were dominant in soils rich in organic matter whilst Prostigmatids were the dominant Acarines in soils with a low organic content. This was also described and reported by Fujikawa (1970) and Singh and Singh (1975). This study corroborates the observations of the above workers.

The differences in the percentage occurrence of the main groups as illustrated using the two types of extractor (Fig 17 and Table 3) demonstrates the importance of establishing the efficiency of a modified or new extraction technique. Goddard (1979) estimated the efficiency of her modified Tullgren to be 70% whilst Gabbutt (1959)

established an efficiency of between 59-88%. Here the efficiency of the chemical extraction unit in terms of individual animals collected was low and estimated at 2% whilst the Tullgren funnel's efficiency was estimated to be between 60-70%.

Despite the low rate of extraction of individuals the chemical unit did extract thirty-six species of Acari and twenty-three species of Collembola whilst the Tullgren unit extracted eighty-four species of Acari and thirty-one species of Collembola. Thus although the chemical unit is of little use for population studies it can be used for collecting representatives of many of the species inhabiting rain forest floors. Compared to the results of Beck (1971) the number of species of Cryptostigmatid mites collected is a little on the low side. He found that on average for Terra firme rain forest he collected forty species of Cryptostigmatid mites, the total number of Cryptostigmatid mite species present being between 110-130. The Tullgren used in this study collected a maximum of thirty species of Cryptostigmatids per sample and overall forty different Cryptostigmatid species. This high number of different species is an indicative and indeed a characteristic feature of the central Amazonian rain forest (Beck 1971).

In conclusion, it must be re-stated that there are many problems encompassed in undertaking collections of soil animals in remote regions. The transport of bulky apparatus and chemicals through the rain forest along narrow trails is only possible with the use of porters which creates further organisational problems. All analytical techniques can pose problems for a worker in the field. The chemical unit in this study failed to perform as well as it did in the trials and the use of the Tullgren funnel poses problems of controlling temperature and moisture gradients. As already described, variations

of the Tullgren technique in the field have been used by Imadate and Kira (1964), Sheals and Hyatt (1964) and Bullock (1966). Imadate and Kira used the sun to dry the samples whilst Bullock preferred a slower extraction under the shade. Sheals and Hyatt (1964) used portable lamps to dry the samples. All these techniques have their advantages and disadvantages. This study attempts to combine the advantages, the samples being dried under an open-walled thatched hut during the day with additional heat being supplied at night from a portable lamp. The evaporation of the collecting fluid was prevented by fitting the phial containing it to the base of the funnel. This however has the disadvantage of reducing air flow and increasing the risk of condensation. Another problem encountered was the disturbance of the funnels by lizards and semi-wild pigs rubbing against the hut's upright posts. As a result there was considerable debris in the collecting phials.

3 A Comparative Study of the Soil Animals in a Rain Forest and Mandiocca Field

3.0.0 Introduction to Soil Fauna in the Tropics

Strickland (1947) introduced his paper with the statement that 'little work had really been carried out in the tropics'. This statement to a large extent still remains valid, compared to the wealth of data from temperate countries. As investigations have been limited in number they still tend to centre around the collection and identification of new species. In the Amazon rain forest it has been estimated that as many species await collection and identification as have been collected, (Bellamy, Smith, Radio 4 1978, 1971); most of these species dwell in the soil. This is more true for the Amazon rain forest than other regions as much of its vast area of 2¼ million square miles has been remote and inaccessible. Modern transport is changing this but rain forest destruction (at the rate of 70 hectares an hour in the world - Bellamy 1982) means that many parts of the rain forest will have been destroyed before it has been studied.

Some more recent studies in the Amazon have centred around investigations of the inter-relationships of soil dwelling fauna, (Fittkau and Klinge 1973).

A few comparative studies have also been undertaken to show the differences in fauna in rain forest and adjacent burnt or cultivated soils, (Lasebikan 1974, 1975, Athias 1978, Springett 1979).

In comparative ecosystems in India, Prabhoo (1976) has compared the soil dwelling micro-arthropods of virgin forest with those from adjoining tea fields. Choudhuri and Banerjee (1975) carried out a similar study of forest and a sparsely vegetated second plot and Singh and Pillai (1975) compared the micro-arthropods of three different crop-producing fields. Singh and Singh (1975) undertook a

study of the organisms in forest litter and soil during the monsoonic rainy season. Other information about the major groups of soil fauna in India has been provided by Mukharji and Singh (1967 and 1970), Singh and Mukharji (1967, 1973), Chaduri and Roy (1967, 1970, 1971) and Gupta and Mukharji (1978). Suleman et al (1979) undertook a general survey of the soil fauna to be found in the grounds of Peshawar University in Pakistan producing a species list.

In comparative ecosystems Salt (1952) compared the arthropod population of soil beneath different types of pasture in East Africa and Belfield (1956) examined the vertical distribution of soil arthropoda in pasture soils during the wet and dry seasons. Data on South African soil fauna has been provided by Graham (1956), Erasmus and Ryke (1965). Loots and Ryke (1966) carried out a quantitative study of the meso-fauna of pasture soils using a Berlese-Tullgren funnel to investigate the seasonal fluctuation of animals in the soil. Lasebikan (1974, 1975) has described the inter-relationships within a soil ecosystem in the tropical rain forests of Nigeria. In particular he studied the distribution of Acarina and Collembola relative to the vegetative cover and the soil's characteristics. In addition he has presented a concise account of the effects of clearing rain forest on the distribution of soil organisms. Ghabour and Wafai Mikhail (1979) carried out a study in the desert near to Gharbarinat. In particular they studied the distribution of soil micro-arthropods in relation to the plant Thymelaea spp. They found that on the windward side of this plant the density of organisms was only $12/m^2$ whereas on the leeward side the figure rose to $33/m^2$. Athias (1978) compared the fauna in the soil of burnt and unburnt savannah in West Africa. He sampled monthly, extracting the animals with a dry funnel technique. The fauna was more abundant in unburnt land particularly beneath coarse

grass clumps. In unshaded areas burning reduced the abundance of micro-arthropods as did the level of soil moisture, soil temperature and the low rainfall. As might be expected burnt areas contained fewer decomposer invertebrates. Similar studies of burnt sites in Western Australia (Springett 1979)confirmed that burning reduces, but does not totally destroy the soil's fauna. There was a reduction in the rate of decomposition which parallelled these changes.

Some very early investigations of tropical sites were carried out in the East Indies by Dammerman (1925, 1937). He calculated the number of soil animals to be found within given areas of Javan and Sumatran forests. More recently studies in Thailand have been undertaken by Imadate and Kira (1964), Aoki (1965) and Ogino (1965). Whilst Bullock (1966), Chiba (1974) and Leow (1974) have carried out studies in Malaysia. Many of these studies related faunal populations to environmental influences.

Several studies have also been undertaken in Central and South America. These and other tropical surveys suggest that soil dwelling fauna in the tropics are less numerous than their temperate counterparts. (Schaller in Peru 1961, Salt 1952, Goodnight and Goodnight 1956). Van Der Drift (1968) working in Surinam disagreed. The vast amount of litter in a tropical rain forest would suggest that there might be large numbers of micro-arthropods feeding on the decomposing litter, but in fact it is fungi that rapidly decompose this litter resulting in a rapid recycling of nutrients within the Amazon rain forest. Van Der Drift demonstrated that in Surinam there were in fact higher numbers of soil invertebrates than in 'comparable' sites in the Netherlands. Strickland (1947) reported a decrease in the soil fauna of a cacao plantation compared to primeval rain forest in the West Indies. This reduction was related to the trampling effects of humans

(Bullock 1967) and the 'change' in plant cover. In both plots he recorded a decline in the number of micro-arthropods in the surface layers as the dry season advanced. There was a tendency for these animals to migrate downwards in response to a decrease in humidity. Bullock (1967) also reported that during the dry season there was also in many species a decline in reproduction which suggests that the reproductive cycle of many species is seasonal. Williams (1941) carried out an ecological study of the rain forest floor in Panama and concluded that tropical soils had more species than temperate soils. He listed 289 species of which 67 were new to science. The average population per square metre was 9,822, but the maximum in some quadrats rose to 19,472. In addition he found that there was no apparent correlation between collections at different times of the day and the number of animals collected although analysis of samples collected at night suggested that there might have been a nocturnal migration of species downwards into the soil.

Serafino and Merino (1979) studying soil and litter fauna in Costa Rican rain forests reported that Acarina and Collembola were the dominant species. This conclusion is supported by other investigations including those of Strickland (1947), Van Der Drift (1968), Singh and Singh (1975) and Beck (1970, 1971). As might be expected, they reported that there was a decrease in population density with increasing depth. They related this to food availability. Again in Costa Rica, Stanton (1979) compared the patterns of species diversity in tropical rain forest with temperate forests in the USA. The diversity of mites was greater in the tropical forest, but other classes of invertebrates were fewer in tropical rain forest; this reduced diversity was inversely proportional to the amount of litter present in the habitat.

Reference has already been made to the first 'by chance' study of Amazonian soil-dwelling organisms undertaken by Beebe (1916). His purpose was to define the feeding behaviour of a tyrant antwren (Myrmotherula spp.). Since then more specific studies have been undertaken. Many of them have been related to the collection and identification of new species (Beck 1967, 1968, 1970, 1971, Schaller 1960, 1961, Salter 1981), but several of these have also presented additional data relating to population density etc. Fittkau and Klinge (1973) have tried to demonstrate the inter-relationships of soil-dwelling fauna in the Amazon rain forest.

Beck (1971) has presented population density data for a few animal groups. His results have served to highlight the dominance of the Acarina and Collembola in the Amazon Terra firme rain forest. Unfortunately his results give little information on the population density and biomasses of ants and termites, yet he assumed that three quarters of the total biomass of soil fauna was made up of ants and termites. His counts are summarised in Table 8. The figures for termites and ants are low as a result of his collecting technique. The total fresh biomass of the soil fauna was found to be 84kg per hectare. Vallejo (1981) surveyed the micro-arthropods living in the 'jungle' soil in the state of Rio de Janeiro. In addition to estimating density and recording the diversity of the fauna he noted litter temperature and moisture level. Fittkau and Klinge (1973) described the role of soil fauna as part of the total biomass and attempted to model the trophic structures operating in the Amazonian rain forest. Figure 18 shows organic matter flow in this rain forest. It shows that energy flow is primarily through the detritus food chain, particularly through the fungi. This conclusion is supported by Went and Stark (1968) and Beck (1970, 1971). Went and

Table 8 - Soil Fauna of Central Amazonian Terra Firme Rain Forest on a Latosol. Numbers are expressed as 10^6 individuals per hectare. (Beck 1970, 1971, after Fittkau and Klinge 1973)

10^6 individuals per hectare	Litter	Upper Mineral Soil	Macro -fauna	Total
Acarina	612	115	-	727
Collembola	103	16.8	0.34	120
Isopoda	0.7	-	0.05	0.8
Pseudoscorpiones	2.1	-	0.09	2.2
Other Arachnida	0.7	-	0.2	0.9
Diplopoda	2.8	-	0.1	2.9
Other Myriapoda	3.5	-	0.03	3.53
Protura	2.8	-	-	2.8
Diplura	1.4	-	0.01	1.41
Larvae of Coleoptera and Diptera	4.0	-	0.04	4.04
Coleoptera	1.4	-	0.07	1.5
Isoptera	0.9	-	0.4	1.3
Formicidae	7.2	-	1.4	8.6
Aphidina/Coccina	39.4	-	-	39.4
Opiliones	-	-	0.02	0.02
Blattaria	-	-	0.02	0.02
Grylledea	-	-	0.05	0.05
Total individuals	782	144	2.8	929
Biomass (kg)	67.7	12	4.4	84

Fig 18 - Schematic Distribution of Biomass and Organic Matter Flow in the Central Amazonian Rain Forest Ecosystem (after Fittkau and Klinge 1973)

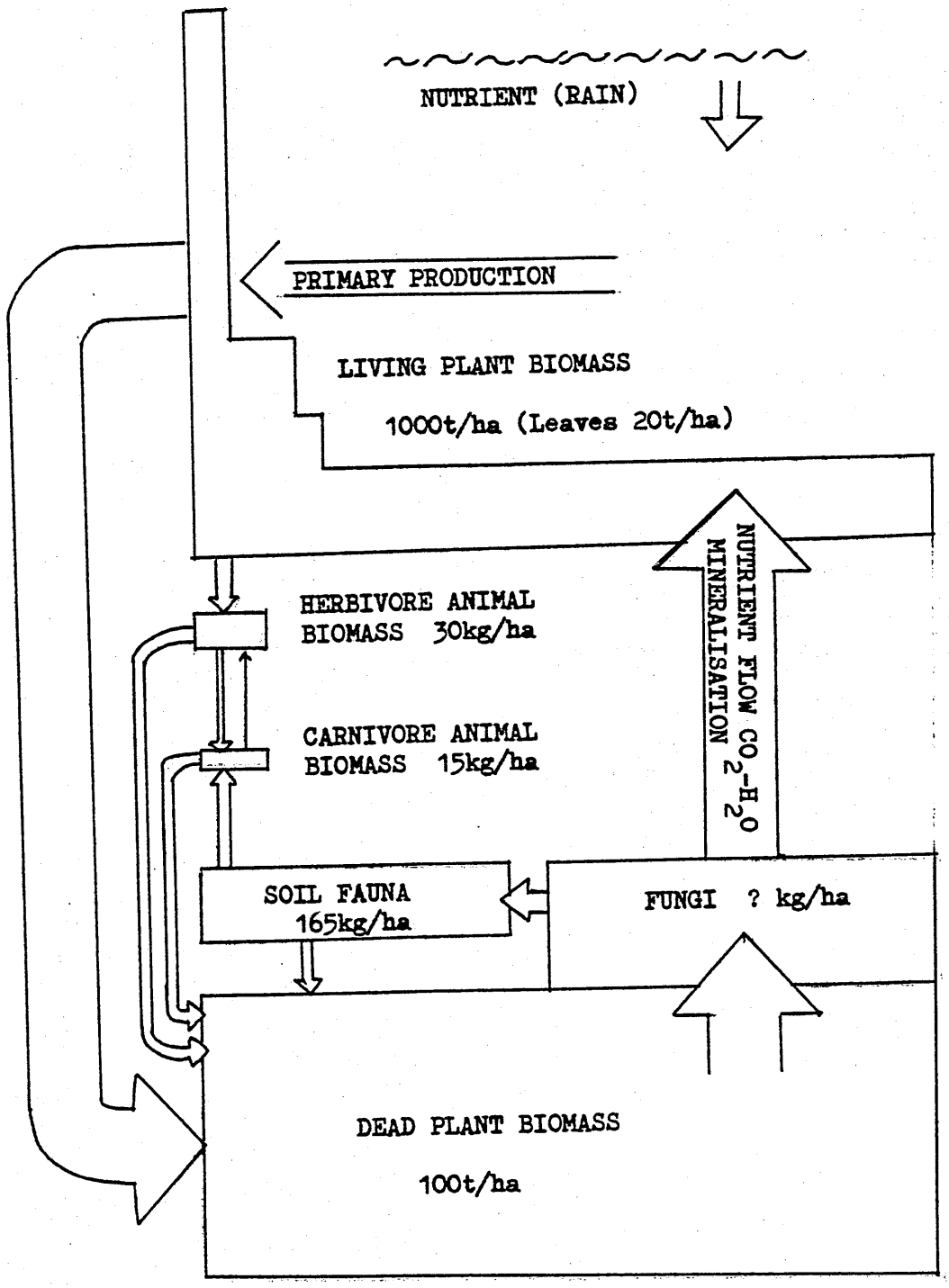
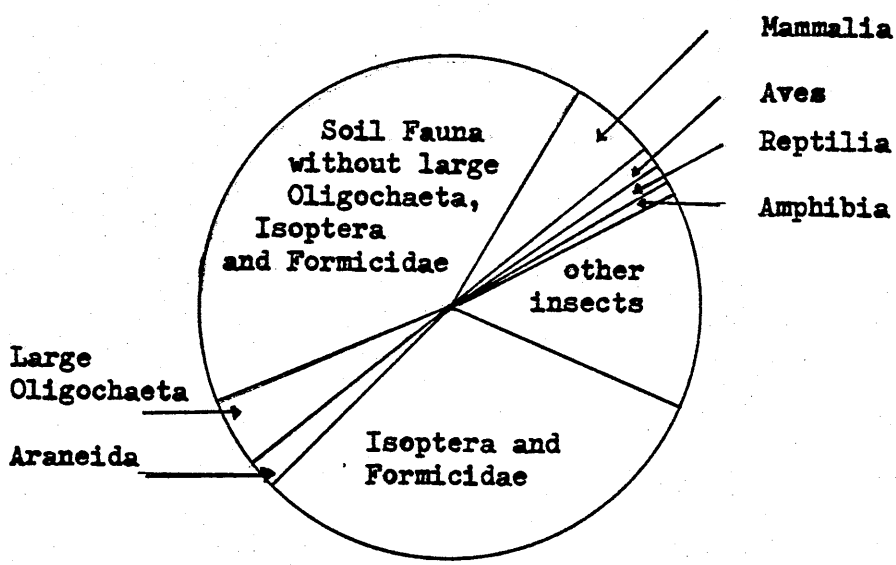


Fig 19 - Composition of Total Animal Biomass (after Fittkau and Klinge 1973)



Stark proposed that the nutrients released by decomposer fungi pass through mycorrhizal fungi to the tree roots and are not released into the soil. This would account for the relatively low fertility of rain forest soils. In fact these authors suggest that the same fungal mycelium acts as primary decomposer and the mycorrhizal symbiont. Soil animals feed on fungi, but also on transformed litter. As they form 50-75% of the animal biomass of the Amazon rain forest they are the most important group of litter organisms in terms of energy flow. A pie diagram showing the relative proportions of different animals can be seen in Figure 19.

3.1 Inferences from Tropical Soil Fauna Studies

It is possible to collate data from the different regions of the world to demonstrate certain common features of tropical forest litter fauna particularly the effects of environmental factors on population density, seasonal abundance etc. These will now be considered.

3.1.1 Soil Population Estimates

It is on the whole generally accepted that tropical soils support less fauna than temperate soils (Schaller 1961, Greenslade 1968, Beck 1971, Plowman 1979). Van Der Drift (1968) has found that soils in Surinam have higher populations than soils in the Netherlands. Beck (1970) and Schaller (1961) support the majority view and point out that in tropical regions the soil micro-arthropods do not function as primary decomposers of litter. Instead this role falls to fungi and micro-arthropods feed on these. Despite the smaller numbers a far greater diversity of species are found in tropical soils. All the work undertaken in the tropics has shown that Acarina and Collembola are the dominant soil animals in terms of numbers (Fittkau

and Klinge 1973), but in terms of biomass, ants and termites form three quarters of the soil fauna in tropical rain forest (Beck 1971).

3.1.2 The Effects of Physical and Edaphic Factors on Soil and Litter Populations

Since the Second World War considerable evidence has been collected which demonstrates that rainfall can affect the numbers of soil animals. After a short lag period the commencement of the rainy season is associated with an increase in the soil fauna (Goodnight and Goodnight 1958, Loots and Ryke 1966, Van Der Drift 1968, Ng 1974, Leow 1974, Lasebikan 1974, Gupta and Mukharjii 1978, Bhattacharya and Raychauduri 1979, Plowman 1981).

The alternative conclusion was reached by Vallejo (1981) in Brazilian 'jungle' (the state of Rio de Janeiro) who found that the fauna was more abundant in drier months but that it had a more even distribution of rain through the month.

Langham (1975) in Malaysia reported a reduction in the soil fauna in both the wettest and driest months of the year, both extremes proving too hostile to micro-arthropods (presumably either waterlogging or desiccating the fauna). Ogino (1965) did notice an increase in the population just after the start of the rainy season but then discovered that the population declined as it reached its peak. He suggested that excess rainfall made conditions unacceptable to the soil fauna which die probably as a result of waterlogging and anaerobic conditions. Beck (1971) compared the soil fauna of regularly flooded rain forest with rain forest that was never flooded in the Amazon basin. He found that regularly flooded rain forest (the Varzea) had lower soil populations than the Terra firme rain forest (never flooded). Williams (1941) pointed out that the level of soil moisture was indicative of conditions in the leaf mould and that

there appeared to be some correlation between this level and the number of soil animals present, eg minute animals with very thin body walls require a very high moisture level.

Langham (1975) has demonstrated that the vertical distribution of organisms can be correlated with moisture contents; the distribution of decomposing material also determines the number of soil animals present, hence most animals are found thriving in the surface layer where most food is available in the form of transformed litter and micro-fungi. This has been confirmed by Whitford et al (1981) who reported that the diurnal migrations of micro-arthropods into the surface litter in a desert is related to the moisture content of the litter; the litter was found to have a moisture content of 7% by weight at 08.00 hours and this fell to less than 1% by midday. Acarines were observed moving into the litter in the early morning returning to the soil by midday. Ng (1974) found that soil fauna moved into litter on rainy days and deeper into the soil in dry conditions. Belfield (1976) found that in a West African pasture most fauna were in the top 15cm (mainly in the top 5cm) during the wet season whilst during the dry season most soil animals had migrated below 15cm in order to avoid desiccation.

It is now generally accepted that the soil moisture level is the most important factor causing fluctuations in the populations of tropical soil-dwelling animals. However other factors have been considered and studied. Williams (1941) in Panama has examined the influence of soil ions (K, Mg, Ca, N, PO_4) and acidity (pH). Bhattacharya and Raychaudhuri (1979) examined the monthly variation in the density of soil micro-arthropods in relation to relative humidity (RH), air and soil temperatures in a monthly sampling programme. Williams (1941) found that variations in

Potassium levels did not affect the distribution of, or the size of the population. He also recorded a marginal preference for neutral soils. Bhattacharya and Raychaudhuri (1979) reported in general a negative correlation between micro-arthropods numbers and pH. This has been confirmed by Hazra, Chondari and Roy (1976) working in West Bengal. They found no strong correlation between pH and Collembolan population at the site. However they decided but lacked confirmation that pH may exert an indirect influence via other edaphic factors. Their results also agreed with the earlier conclusions reached by Davis (1963) and Dhillon and Gibson (1962). However Hagvar (1980) found that soil pH influenced the success of colonisation. Each species responded individually to a raised or lowered pH. He also reported that acidity also influenced the success of faunal reproduction. Plowman (1981) compared a wet sclerophyll forest with a sub-tropical forest in Australia and reported finding differences between species composition in the two habitats and found that these differences could be correlated strongly with soil pH.

Bhattacharya and Raychaudhuri found in addition that the Collembolan populations showed a significant positive correlation with monthly RH and air temperature recordings.

Athias (1978) working in burnt and unburnt West African savannah noted that the horizontal distribution of micro-arthropods was heterogeneous, and that their abundance was greater in soil beneath grass clumps. In unshaded areas burning controlled the abundance of soil fauna. He also found that soil temperature induced a migration of animals into the lower layers of soil. This was also recorded by Gupta and Mukharjii (1978), Athias (1978), Springett (1979) and by a postgraduate working in Schubert's laboratory in Manaus, Brazil; they have all discovered that although burning (at temperatures up to

600kw/ha) severely reduces the population some of the animals survive either in the deeper layers of the soil or as eggs, larvae or pupae. As a result of burning, decomposition rates slowed but the addition of free nutrients released following combustion led to a soil fauna population explosion; this is explained by the increased availability of food per individual and the decreased levels of predation in the habitat. The growth of the population post-burning was therefore faster than for fauna from a similar but unburnt habitat.

Murphy (1955) reported that particle size and the number and size of the pore spaces were important in determining the numbers of soil animals present in a sample. Holt (1981) working in Australia found that although larger Cryptostigmata (Acarina) were not influenced by the size of the soil pores, smaller species were found in association with smaller pores in the samples. Smaller pores were shown to be indicative of the presence of long narrow Cryptostigmatids rather than short, wide-bodied forms.

Research has been carried out in both tropical and temperate regions into the effects of soil compaction on soil communities. Newton and Pugh Thomas (1979) found that trampling affects the distribution of soil animals as a result of compacting the soil. Hermosilla (1981) looked at the effects of cattle grazing on Argentinian soils. He measured the degree of compaction using a dynamometrical needle. He found that Tarsonemidae (Prostigmatid mites) and Acaridae (Astigmatid mites) numbers increased with compaction whilst Oribatid, Gamasid and Prostigmatid numbers decreased as compaction increased. Bigot (1978) studied the effects of horses in the Camargue. He noted particularly that Collembola decreased in number in heavily trampled and hence compacted soil whilst some Acarine species increased in density. Damage to soil fauna populations in cacao populations by human trampling

has been reported by Strickland (1945).

3.1.3 Results from Earlier Comparative Studies

In previous studies descriptions of the habitat at the collection site have proved to be limited and crude providing the reader with the minimum of detail. Little attempt has been made to relate the habitat to population figures - Bullock (1966).

Dammerman (1925,1937) and Beebe (1916) carried out early investigations into the fauna of tropical soils, the former in the East Indies and the latter in Brazil. In both these studies the features of the habitat were only described in very general terms, as they were by Bullock (1966). However Williams (1941) working in Panama did attempt to relate the distribution of soil dwelling animals to environmental factors although in very general terms. Strickland (1947) in his account of his studies in the West Indies comparing the soil fauna of the savannah with a cacao plantation having similar soil types indicated that faunal differences were related to the plant cover at each site and to the effects of man's trampling. Maldague (1958) in the Congo compared the fauna of a forest with grassland finding that the first habitat supported more Acari. In a later paper with Hilger (1968) he suggested that faunal differences were related to the amount of litter present on each site and that abiotic factors determine the density and composition of the soil community. Van Der Drift (1968) compared the litter and soil fauna of cultivated land and rain forests in Surinam showing that in recently reclaimed land the number of soil micro-arthropods was small and that cultivated lands supported populations 40% lower that that of rain forest. Ants were more common in the cultivated fields and the micro-arthropod population averaged 80% of that in the rain forest which surprised him as he was expecting the fields to support much lower

populations than the forest. Loots and Ryke (1966) investigated different types of pasture in South Africa in order to evaluate seasonal fluctuations in the micro-arthropod populations.
More recent comparative studies include those of Lasebikan (1974, 1975), who clearly described in detail the habitat of Nigerian rain forest prior to clearance. He then looked at the effect clearance had on soil populations. Singh and Pillai (1975), Choudhuri and Banerjee (1975) and Prabhoo (1976) have all compared soil populations at two or more different sites in India. Plowman (1979, 1981) compared the litter and soil fauna of two sub-tropical forests in Australia and suggested that litter and soil fauna should be distinguished as both supported unique faunal species.
Bullock (1964) showed that bare ground supported less fauna than soil beneath established plants of pyrethum and grass tussocks.
Strickland (1945, 1947) discovered that soil fauna migrated downwards at the onset of the dry season. The cacao plot had a richer fauna than the savannah. Despite the trampling effects of man the increased amount of litter and organic matter in the plantation resulted in a greater number of families, genera and species.
Van Der Drift's (1968) results support this in that rain forest soils have a greater population of micro-arthropods than adjacent cultivated fields having less litter. He found that manuring increased the size of the micro-arthropod fauna in cultivated areas in the process demonstrating the significance of organic matter as a factor influencing population size in the soil. This is corroborated by Singh and Pillai (1975) who found that of four cultivated fields studied, a banana field's soil supported the largest population of micro-arthropods. This was related to this field having higher levels of soil moisture and organic matter. Prabhoo (1976) found

that similar features in a rain forest resulted in higher populations of Acari and Collembola than in adjacent tea fields with few exceptions, namely that Symphalids (Myriapoda) preferred the tea fields soil and that the rain forest soil had definite L, F and H layers that were not clearly defined in the soil of the tea field. Wallwork (1967) showed that the more definite these layers were, the greater the micro-arthropod population.

In a personal communication, Dr H Schubart indicated that two post-graduate students working in his laboratory were comparing micro-arthropod populations in Amazonian rain forest soils with those from recently burnt sites and a cultivated field. Unfortunately it has proved impossible to locate these students' results. However Dr Schubart has told me that their results suggested that burning did not destroy the total population and rain forest supported more fauna than the cultivated field. Only one other comparative study in the Amazon basin seems to have been undertaken and this is by Beck (1971) who has carried out more work on soil fauna in Amazonia than any other person. He compared the soil fauna of Terra firme and Varzea forest. His results demonstrated that the Terra firme soils supported a larger and wider range of species than the Varzea. In the former, three clearly defined habitats in the soil were detectable and each supported distinct groups of animals. These divisions were not evident in regularly inundated Varzea soils. The latter had a low number of endemic species despite being richer in nutrients. Beck suggested that flooding resulted in conditions too hostile for the majority of soil dwelling micro-arthropods.

The effects of clearing plant cover by burning has been examined by several workers in the tropics. Athias (1978) studying the after-effects of burning savannah reported an initial sharp decline in the

soil population although after a short time lag there was a population explosion resulting from the increased levels of nutrients in the ash. Lasebikan (1975) described the effects that clearing Nigerian rain forest from a site had on the soil population; after clearance (not by burning) the population declined in density and species composition. The response of individual species varied although with the exception of the Coccidae (Hemiptera), Uropodidae and Gamasina (Acari) all other faunal groups and species declined in numbers. He related the population decline to several factors:

1 Increased exposure of the soil to the sun resulting in greater temperature extremes.

2 Exposure to rainfall resulted in greater raindrop impaction destroying crumb structure.

3 Reduction of litter cover reducing food levels and the availability of shelter.

4 Loss of humus and the resulting effects on the population.

3.2 Aim

In this section of this study a comparison between a rain forest site (site 2) and an established two year old mandiocca field (site 1) is drawn. In addition, three samples were taken from a burnt and cleared plot of rain forest to see if any soil animal could survive burning. This site had been cleared only a few days prior to sampling. The soil was covered in a layer of grey ash to a depth of 1-2cms. Fallen and standing large tree trunks were still smouldering. The ash temperature averaged 1°C higher than soil in the mandiocca field.

3.3 The Study Sites

3.3.0 Introduction

The studies described in this paper were undertaken during two expeditions to a remote region of the Amazon basin comparatively close

to a small settlement called Carauari sited on the banks of the Rio Jurua in 1978 and 1981. This river is a tributary of the Solimões (Upper Amazon). Carauari is about 600km from the mouth of the Jurua at Lat. 4°52' 48" S, Long. 66°53'34" West. No previous scientific studies of the soil fauna had been undertaken within 1000km of the site.

Leading West from the 'town' is a narrow rubber tappers' trail. As the distance from the town increases so the trail dwindles until it becomes difficult to follow. Two sites were selected along this trail as being suitable for this study.

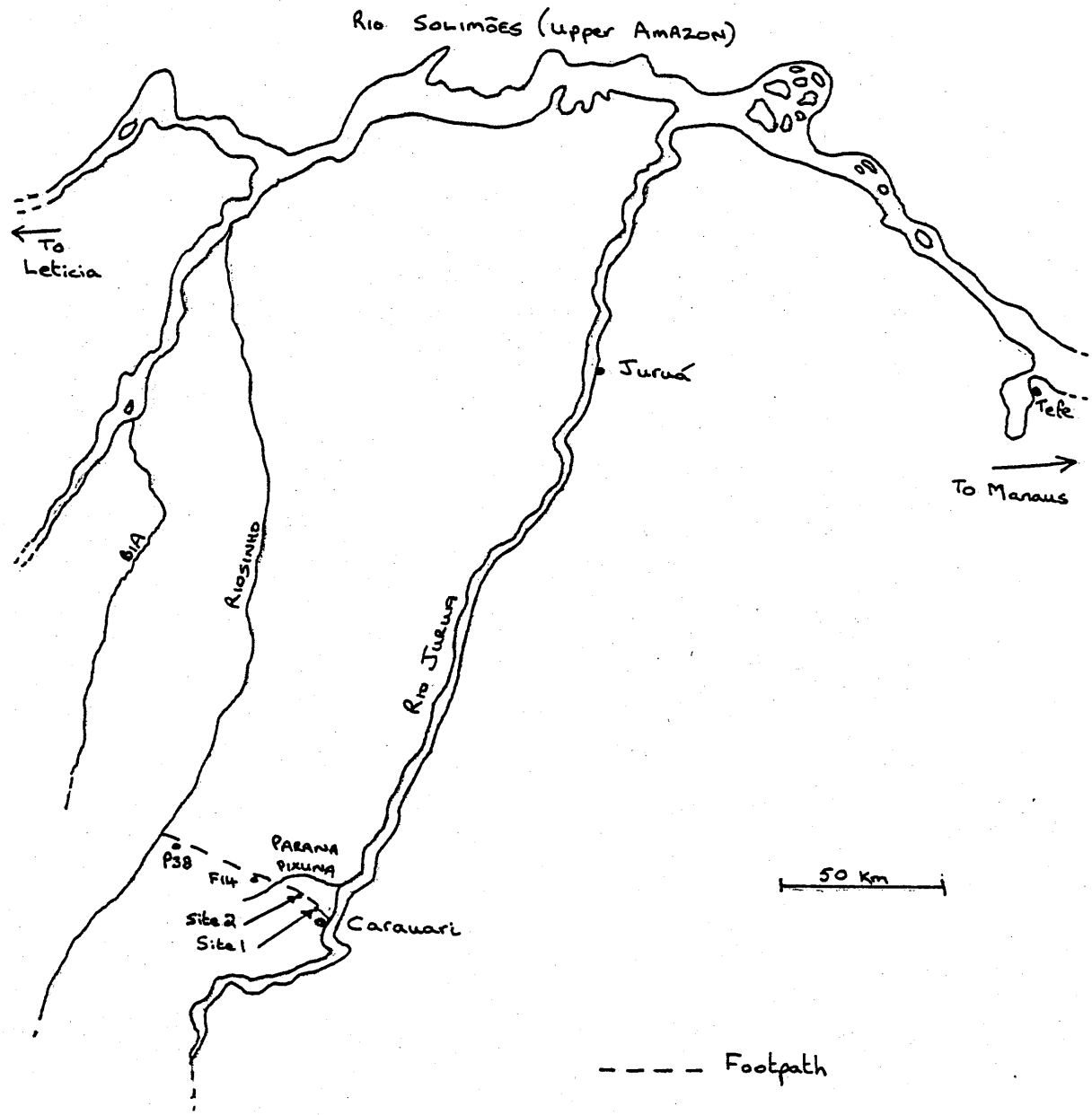
3.3.1 Site 1

This was situated 7km from Carauari. It consisted of a mandiocca crop on ground cleared two years ago. Each plant was on average between one and two metres tall. Interspersed between these plants were clumps of various species of grass. The surface of the soil had only a thin layer of litter (0.2cm) with a humus layer of 0.5cm underneath. The rest of the soil profile is similar to that of site 2. Mandiocca is harvested prior to leaf-fall and the surface litter in the middle of the plot consisted of a few shed mandiocca and weed leaves and additionally a few rain forest tree leaves that had drifted onto the plot from the surrounding rain forest. The soil's pH was slightly acidic, pH6. The mandiocca field was about 1 hectare in size.

3.3.2 Site 2

The second site was situated adjacent to the expedition campsite a further five kilometres along the trail. It was thought better to sample away from the mandiocca plot as the rain forest bordering a pioneer farm was likely to have been influenced by human trampling of the forest floor whilst harvesting game and wood. The selected

Sketch Map to show Radambrasil and This Study's Sample Sites



P38, F14 : Radambrasil Sites

Site 1, Site 2 : This Study's Sites

Plate 3 - Site 1 Mandiocca Field

Plate 4 - Site 2 Interior View of Rain Forest

Plate 5 - Close-up of Rain Forest Floor

Plate 6 - Site 3 immediately prior to clearance by burning

site was bordered on the south side by a shallow stream. It was bisected by a narrow trail that ran at ninety degrees to the rubber-tappers' trail which bordered the site on its east flank. One of the characteristics of this Terra firme rain forest is the vast variety of tree types within the forest generally but also in this small site. The lowland forest bordering the site was dense (as was the site) and was interspersed with a mixture of natural open palm forests. Despite the poor soil reported by Radambrasil (1977) the forest was built up of a wide variety of tree species. The most numerous tree species in the area were described by Radambrasil (1977), a company which investigated two sites (P38 and F14) along the trail as part of a survey of the entire Brazilian Amazonian basin (Volume 15). Both these sites were close to Site 2. The main tree types were:

Eschweilera odora, Pouteria lauriflora, Licania pruinosa, Saccoglottis guianensis, Iryanthera macrophylla, Nyroxilum balsano, Prieurella prieurii. The dominant species in Site 2 was without doubt Cecropria spp., which varied in height from 20-30 metres.

The forest ranged in height from 20-30 metres high and was characterised by a lack of emergent trees above the canopy. This layer was poorly represented by Eschweilera spp,, Mazilaurus spp. and Copaifera spp. It is worthy of note that the Varzea rain forest close to the Jurua was composed of many different genera and species.

The Varzea soils were not sampled on this project but were reported by Radambrasil to be a mixture of eutrophic alluvial and eutrophic humic gley soils; these were regularly flooded and as a result had a relatively high fertility compared to the Terra firme forests. The latter in this area were described by Radambrasil as being 'generally plinthic podsolic soils, humic (plinthic) latosol and

quartz sand mixtures' - having a relatively low fertility. The rain forest soil was acidic with a pH varying from pH 4-6. The author's own figures confirmed those recorded by Radambrasil.

In 1978 a soil trench was dug in order to record details of the soil profile. This agreed to some extent with the profiles carried out by Radambrasil at the two sites known as P38 (Lat. 4°47' South, Long 66°81' West) and F14 (Lat. 4°50' South, Long. 66°56' West). Site 2 in this study was approximately Lat. 4°51' South, Long. 66° West. The soils described by Radambrasil were a red-yellow clay podsol that developed from the sedimentation resulting from the formation of the Rio Solimões during the late Pliocene or early Pleistocene era. The land is well drained and flat with a 2° incline in places. The Brazilian soil layer classification system is a little unusual and gives the following description of the podsol at site P38:

Layer	Depth	Description
A1	0-5cm	Darkish-yellow soil (10YR5/6) with small granular particles. Pliable and workable. Clear transition zone.
A3	5-20cm	Darkish-yellow clay (10YR5/8), small granular particles. Crumbly, pliable with a gradual transition to:
B1	20-40cm	Strong, darkish (7.5YR5/6). Very porous soil broken into many small subangular particles. Crumbly, pliable. Gradual transition to:
B21	40-70cm	Red-yellow (5YR5/8), clearly clay, small subangular particles, crumbly and pliable; diffuse transition into:
B22	70-100cm	Red-yellow (5YR5/8), identical to B21.

The figures in brackets refer to standard colour charts used by

Radambrasil.

The profile dug in 1978 produced additional information on the litter and humus layers and unlike the profile at P38 all the layers described were clearly defined and are classified according to D K Mc E Kevan (1962).

Layer	Depth (Variable)	Description
Litter	0-3cm	Various fallen leaves. Variable according to site.
Humus	3-8cm	Decaying organic matter, rootlets and mycorrhiza. Spongy yet 'tough'.
A1	8-12cm	Pale brown, no stones.
A2	12-22cm	Pale brown, aggregations of clay.
B1	22-38cm	Clay/sandstone-like layer (darkish white-yellow). Crumbly.
B2	38-47cm	Red clay layer. Crumbly.
B3	47-57cm	Grey clay layer with red tinge.

The main difference between P38 and the experimental site podsol appears to be the lowermost grey clay layer found at the experimental site. There is no apparent reason for this difference and the literature does not indicate any sites with similar soil structure.

3.3.3 Environmental Data Collected during Sampling

The temperature of the air beneath the rain forest canopy varied between 21-31°C, averaging 25°C whilst the temperature at the soil surface varied between 22-28°C, averaging 24.5°C. As expected, in an unshaded region the average air temperature above the mandiocca field was 28.9°C whilst the surface soil temperature was 25.8°C. During the six weeks spent at the site from the middle of July to the end of August (1978 and 1981), it rained on average for a short period of time every other day, usually during the late morning or

early afternoon. RH beneath the canopy was measured at the time of sampling and ranged from 83-95%.

3.4 Method

The sampling procedure has been previously described in Section 2.3. As Site 1 was five kilometres from the base (and also Site 2), it was decided that all sample cores (10cm diameter x 5cm deep) would be transported from both sites in plastic bags in an undisturbed state. This study took place in 1978 when equipment was at a premium so all samples were subjected to chemical extraction using turpentine as a repellent. As a result of this technique's poor extraction efficiency it is not possible to present reliable population estimates as numbers of animals per square metre.

Samples taken at Site 3 were collected in the same way from the middle of the burnt hectare and were then treated in an identical fashion to those of the other two sites.

3.5 Results

The mean number of soil micro-arthropods and other fauna per sample of rain forest, mandiocca and cleared sites is given in Tables 9 and 10 with additional information relating to percentage occurrence being presented in Fig 20 and Table 11. Table 12 shows the difference in the number of Acari and Collembolan species collected at Sites 1 and 2. Table 9 shows that the populations of the rain forest and mandiocca sites are not significantly different for the majority of faunal groups excluding Astigmatid mites, Sminthurid Collembolans and Isopterans all of which are present in significantly larger numbers in the rain forest samples.

Table 10 (and Fig 20) shows that with the exception of Cryptostigmatids the relative abundance of the Acari is very poor in the mandiocca field (Table 11, Fig 20) and Prostigmatid, Astigmatid and Mesostigmatid

Table 9 - A Comparison of the Litter and Soil Fauna of a Cultivated Mandiocca Field and Rain Forest Using A Chemical Extraction Unit Sampled to a Depth of 5cm from the Surface

Site / Animal Group	Arithmetic Means.		Transformed Means = LOG(n+1)			't' Test	Level of Significance	Sign. Better Area
	Mandiocca	Jungle	M	J	SE			
Arthropoda								
Arachnida								
Pseudoscorpiones	-	0.125	-	0.038	0.02570	1.4785	-	-
Araneae	0.083	0.125	0.025	0.038	0.03591	0.36201	-	-
Acari								
Prostigmata	0.083	0.25	0.025	0.067	0.04477	0.9381	-	-
Gamasina	0.083	0.125	0.025	0.038	0.03591	0.36201	-	-
Rhodacaridae	-	0.125	-	0.038	0.02570	1.4785	-	-
Uropodina	-	0.062	-	0.019	0.01881	1.010	-	-
Astigmata	-	0.375	-	0.105	0.04149	2.53073	2%	J
Cryptostigmata	1.833	2.25	0.284	0.383	0.13048	0.75873	-	-
Collembola								
Onychiuridae	0.666	0.187	0.155	0.057	0.07498	1.30701	-	-
Poduridae	1.000	0.875	0.201	0.218	0.09494	0.17906	-	-
Isotomidae	0.583	0.812	0.151	0.202	0.08103	0.62939	-	-
Entomobryidae	0.25	1.87	0.075	0.323	0.09008	2.7531	2%	J
Sminthuridae	0.333	0.625	0.090	0.143	0.07405	0.85077	-	-
Other Insects								
Diplura	-	-	-	-	-	-	-	-
Thysanura	0.083	-	0.050	-	0.03382	1.47841	-	-
Diptera	0.5	1	0.140	0.213	0.08533	0.85550	-	-
Coleoptera	2.083	1.56	0.387	0.328	0.11609	0.50822	-	-
Lepidoptera	-	0.25	-	0.043	0.04362	0.98578	-	-
Thysanoptera	-	-	-	-	-	-	-	-
Hemiptera	1.08	0.625	0.245	0.143	0.09464	1.07776	-	-
Psocoptera	-	-	-	-	-	-	-	-
Hymenoptera	1.166	2.125	0.198	0.384	0.11734	1.2783	-	-
Orthoptera	0.166	-	0.050	-	0.03382	1.47841	-	-
Isoptera	-	0.687	-	0.161	0.05798	2.77681	1%	J
Myriapoda								
Chilopoda	0.083	-	0.025	-	0.02508	0.99681	-	-
Diplopoda	0.166	0.312	0.050	0.086	0.05223	0.68925	-	-
Pauropoda	0.25	0.062	0.065	0.019	0.04880	0.94262	-	-
Symphyla	0.083	0.062	0.025	0.019	0.03135	0.19138	-	-
Platyhelminthes	-	-	-	-	-	-	-	-
Nematoda	-	0.062	-	0.038	0.02570	1.47859	-	-
Enchytraeidae	0.916	1.125	0.205	0.258	0.09765	0.54275	-	-
Lumbricidae	0.166	0.312	0.050	0.062	0.05737	0.20916	-	-
Isopoda	-	0.125	-	0.019	0.01881	1.01010	-	-
Gastropoda	0.166	-	0.050	-	0.03382	1.47841	-	-

Table 10 - The Percentage Occurrence of Fauna in the Soil and Litter of Rain Forest and a Mandiocca Field Sampled to a Depth of 5cm

Animal Group	Sample Site	
	Rain Forest	Mandiocca
Collembola	27.03	22.51
Prostigmata	1.55	0.66
Astigmata	2.32	0
Mesostigmata	1.93	0.66
Cryptostigmata	13.92	14.57
Other arthropods	42.89	51.64
Other groups	10.04	9.93

Fig 20 - Comparison of Percentage Composition of Fauna in the top 5cm of Littered Soil in a Rain Forest and Mandiocca Plot

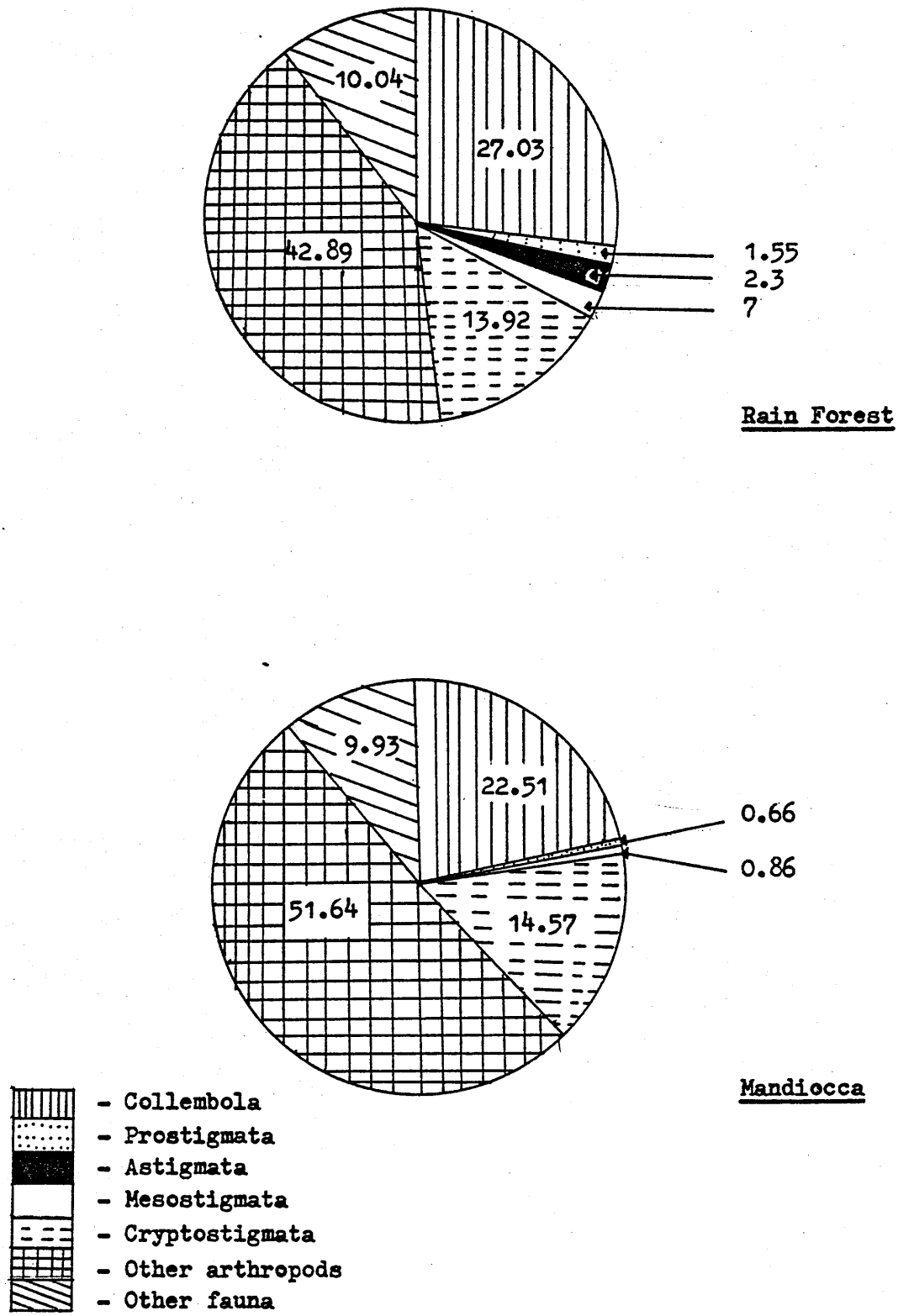


Table 11 - Comparison of the Number of Species of Acari and Collembola collected from the Litter and Soil of a Rain Forest and a Mandiocca Field using the Chemical Extraction Unit

Animal Group	Number of Species Collected at Sample Site	
	Rain Forest	Mandiocca
Prostigmata	4	1
Mesostigmata		
Gamasina	3	1
Rhodacaridae	3	-
Uropodina	3	-
Astigmata	4	-
Cryptostigmata	19	5
Total Acari	36	7
Onychiuridae	2	1
Poduridae	4	3
Isotomidae	8	3
Entomobryidae	8	2
Sminthuridae	1	1
Total Collembola	23	10

Table 12 - Mean Results for a Burnt Site Sampled using Chemical Extraction Unit (Size 5cm deep x 10cm diameter)

Animal Group	Arithmetic Means of 3 samples
Arachnida	
Pseudoscorpiones	0.333
Araneae	-
Acari	
Prostigmata	-
Gamasina	-
Rhodacaridae	0.666
Uropodina	-
Astigmata	-
Cryptostigmata	0.333
Collembola	
Onychiuridae	0.333
Poduridae	-
Isotomidae	-
Entomobryidae	-
Sminthuridae	-
Other Insects	
Diplura	-
Thysanura	0.666
Diptera	1.666
Coleoptera	2.0
Lepidoptera	-
Thysanoptera	-
Hemiptera	-
Psocoptera	-
Hymenoptera	0.666
Orthoptera	-
Isoptera	-
Myriapoda	
Chilopoda	-
Diplopoda	-
Pauropoda	-
Symphyla	0.333
Other Animal Groups	
Platyhelminthes	-
Nematoda	0.666
Enchytraeidae	-
Lumbricidae	-
Isopoda	-
Gastropoda	

mites are weakly represented. Entomobryid Collembolans are also poorly represented at Site 1. There was little difference in the percentage of arthropods (other than Acari and Collembola) at both sites and constituted 42.89% at Site 2 (rain forest) and 51.64% at Site 1 (mandiocca field). As neither apparatus was ideal for collecting non-arthropods the figures of 10.04 and 9.93% would likely be exceeded if more suitable extraction techniques such as a wet Tullgren technique or a flotation technique had been employed.

Table 11 clearly indicated that the rain forest litter and soil supported a far wider range of species of Acari and Collembola than the mandiocca field. This supports the work of Beck (1970, 1971) and Lasebikan.

It was surprising to find animals in the ash so soon after rain forest clearance at Site 3 as indicated in Table 12. Specimens of Pseudoscorpiones (Arachnida); Rhodacarid and Cryptostigmatid Acari; Thysanura, Diptera, Coleoptera, Hymenoptera (all insecta) were collected just a few days after burning.

3.6 Discussion

The inefficiency of the chemical extraction unit has been described in the discussion in the preceding section. It is therefore impossible to present reliable population estimates of soil and litter fauna for the mandiocca and rain forest sites using this apparatus so here discussion must concentrate on the differences between the sites.

The difference between Sites 1 and 2 in terms of plant cover was a significant feature of this study. Site 1 was a mandiocca field established approximately two years prior to the time of sampling. As such, its fertility in terms of the level of organic matter was less than the rain forest but not as low as that found in fields established for six years. Six years is the time generally accepted

to reduce fertility in Amazonian rain forest soil after clearance to such a low level that there is a danger of it becoming desert-like. The dominant plant in Site 1 was the mandiocca plant and these varied in height from one to two metres and were spindly bearing leaves only in the region of their growing tips. Between them were to be found various grasses and other unidentified weeds. The site is not trampled by man during the growth of the plant. Thus there is little shade at the soil level. The rain forest site (2) has been described in depth in Section 3.2. It consisted of mature trees 20-30 metres in height interspersed between a host of tall, spindly younger trees fighting for survival. One hectare of rain forest can contain 93,780 dicotyledonous trees and palms reaching almost 40 metres in height (Fittkau and Klinge 1973). The forest cover reduced the available sunlight to one-one hundredth of its strength creating dark conditions on the forest floor which were interrupted by shafts of sunlight filtering through the spaces created by trees which had fallen. Consequently there were very few herbs and shrubs growing at this site. The rain forest site had a litter layer up to 3cm deep whereas the mandiocca field had only a very shallow layer of litter not more than 0.2cm in depth. The temperature reading obtained in the rain forest at Site 2 showed that both air and soil temperatures were lower than those collected at Site 1 (differences of 1.3°C and 3.9°C respectively). The soil at Site 1 was subject to greater insolation and was therefore dryer than the soil and litter at Site 2. There was little variation in the soil pH of the two sites, the mandiocca field having soil with a slightly higher pH than the rain forest.

Table 9 suggests that the Mandiocca field supports a similar sized soil and litter population to that of the rain forest but it is not possible to present reliable estimates. This would differ from the

general pattern of results that have emerged from other workers on tropical soil fauna who have shown that soils richer in organic matter (as the rain forest soil certainly was) support larger populations of soil organisms (Strickland 1947, Bullock 1967, Lasebikan 1975, Singh and Pillai 1975). This study's results do however agree with the findings of Van Der Drift (1968) in Surinam whose results demonstrated that the micro-arthropod population of a cultivated plot adjacent to rain forest was 80% of the rain forest's population. It is unlikely that this study could result in a similar conclusion as there are significant differences in the plant cover, litter and humus layers and soil temperature of the two sites and the evidence of the previously mentioned workers suggests that these factors affect the size of the soil population to be found in soil and litter samples. These results demonstrate the inefficiency of the chemical unit to extract fauna from rain forest sites having a high soil moisture level and the unit's increased efficiency when extracting fauna from dryer soil samples having little litter. This creates the false impression that the two sites have similar faunal populations. Fletcher (1976) has pointed out that different extractors have different efficiency levels for different soil types and this appears to be the case in this part of the study. It also illustrates the difficulty of comparing the results from two different sites as previously described by Bullock (1967) who proposed that suitable extraction techniques should be selected for each site as one cannot assume that the extraction from different soil types will be similar. The results in Table 9 are consistent with that view. The percentage occurrence of different faunal groups is shown in Table 10 (and Fig 20). With the exception of the Cryptostigmatid mites (14.57%) the Acarina are poorly represented in the mandiocca field. In the samples from the rain forest using the chemical

extraction unit's results, Prostigmatid mites constituted 1.55%, Astigmata 2.32% and Mesostigmata 1.93%. In the mandiocca field these groups results are as follows:- 0.66%, 0%, 0.66% respectively. The percentage of Collembola at both sites was very similar: 27.03% in rain forest and 22.51% in the field.

Only five species of Cryptostimatid mites were collected from Site 1 together with one species of Gamasina and one species of Prostigmatid mite. Despite the inefficiency of the extraction unit this illustrates quite clearly that the Acari were poorly represented in the cultivated plot. Using an identical technique a total of nineteen species of Cryptostigmatid mite, four species of Prostigmata, three species each of Gamasina, Rhodacaridae and Uropodina, and four species of Astigmata were collected from the rain forest samples. This shows that the rain forest samples supported a much more diverse range of species. Beck (1971) found similar results related to the much higher organic content in the L and H layers of the soil. It is possible that the abundant and varied fallen leaves favoured a wider range of species. As previously described in this study eighty-four species of Acari (mainly Cryptostigmata) were collected from the rain forest samples. Beck (1971) estimated there to be one hundred to one hundred and ten species of Cryptostigmatid mites in the Amazonian rain forest soil samples.

Only ten species of Collembola were collected from the mandiocca field. Twenty-three species of Collembola were collected in the samples from the rain forest site. This again is indicative of the reduced litter and organic matter content of the site. The litter present was similar (mainly mandiocca leaves). This formed only a very thin layer (0.2cm) of the soil. In addition the removal of the rain forest and its subsequent replacement with a food crop provided less shade for the

soil which was subjected to greater insolation resulting in greater temperature extremes. This together with the lack of litter resulted in the soil being dryer. Consequently the cultivated field supported a smaller range of fauna than the rain forest which had higher organic matter and moisture levels and was not subject to insolation to any great degree. These results corroborate the results and findings of Lasebikan (1975), Niijima (1971) and Singh and Pillai (1975).

At both sites Acari were the dominant animal group present in the samples. The second largest group was made up of the Collembola. This pattern has been reported by many tropical soil zoologists including Ryke and Loots (1967), Marcuzzi and Venezia (1972), Singh and Mukharji (1973) and Singh and Pillai (1975).

It was not possible to measure the intensity of heat produced during the clearance of the rain forest at Site 3. Visually it was very intensive and it gave off tremendous heat sending great clouds of grey-white smoke up into the sky. Athias (1976) studying the effects of burning on savannah recorded an intensity of 600kw/ha. Table 12 shows that burning greatly reduced the population of the litter and soil but did not totally destroy it. Representatives from the following groups were collected from three random samples collected from Site 3: Pseudoscorpiones (Arachnida), Rhodacaridae (Acari), Cryptostigmata (Acari), Onychiuridae (Collembola), Thysanura, Diptera, Coleoptera, Hymenoptera, Symphyla (Myriapoda) and Nematoda. All specimens had been represented at Site 2. Many of those collected were probably arrivals post-burning as they had good powers of movement any many were predators. This latter group included ground beetles and Hymenopterans. Dipterans collected were saprophytic and active fliers. More remarkable is the presence of a small surviving

number of Acari and Collembola collected in the samples from the middle of the site. Since it was only two days after the burning the most reasonable explanation of their presence is that at the time of burning they were in the deeper layers of the soil migrating upwards following the burning and the return of lower temperature. The significant decline in the population is expected and follows a similar pattern to that recorded by Lasebikan (1975).

Summary

As a result of unforeseen circumstances - mainly the problem of importing equipment into Brazil - it was not possible to achieve all the initial objectives of this study. However sufficient raw materials were obtained in Brazil to make up some equipment used in the first visit (1978) and at the second visit (1981) sufficient material was taken into the area.

i) A survey of the range of extraction methods used by other workers is given. These are divided into two main groups according to the type of extraction: Dynamic - behavioural methods that rely on the response of the animals to stimuli, and Mechanical - techniques that do not rely on the behaviour of soil animals.

ii) Many of the techniques described here are necessarily laboratory based and are unsuitable for use in remote regions. Therefore the techniques that can be used in the field are described in more detail.

iii) Bullock (1967) suggested that chemical repellents might provide an alternative means of faunal extraction in remote regions. However research has revealed that only a few chemicals had been tested for use in extractors, namely chloropicrin, 'Gamexane', DMP, DNOCHP and Naphthalene. Turpentine had been used by Evans (1933) and Lewis (1960) to extract insects from flower heads. Tests by the author in England revealed that the chemical extraction unit using turpentine as a repellent extracted soil fauna from temperate oak woodland as efficiently as a Tullgren funnel.

iv) This study therefore compares the efficiency of a chemical extraction unit using turpentine as a repellent with a dry Tullgren funnel in order to determine which was a more suitable and efficient field extraction unit suitable for the collection of soil fauna in tropical rain forest. The chemical unit described is the author's

modification of Lewis's apparatus (1960). The Tullgren funnel used is a simple plastic funnel fitted with a 2mm gauge gauze.

va) The chemical extraction proved to be more efficient than a hand-sorting technique but had a much lower relative efficiency than a dry Tullgren funnel using heat at night when extracting fauna from tropical rain forest soil (from the surface to a depth of 5cm).

vb) The mean number of specimens collected per sample as shown in Table 2 for the Tullgren apparatus was 432.2, the minimum number of specimens per sample was 279 whilst the maximum number was 1,009. Using a chemical extractor the mean number of specimens per sample was 16.16, the minimum 3 and the maximum 40 specimens per sample. The rain forest soil and litter fauna population has been estimated at 53,435.8 specimens per square metre (using Tullgren funnels). This figure compares well with the results of soil populations in other tropical regions.

vc) Using a dry Tullgren funnel, eighty-four spp. of Acari and thirty-one spp. of Collembola were collected from the rain forest soil samples. A characteristic feature of the Amazonian Terra firme rain forest floor is the large variety and number of species present. Beck (1970, 1971) estimated the total numbers of Cryptostigmatid mites to be one hundred and ten at Terra firme rain forest one thousand miles away. This study corroborates the work of Beck (1970, 1971) that is, that the Amazonian rain forest soil supports a wide range of species.

vd) Although of little use in terms of population assessment the chemical extractor in its present form using turpentine as a repellent would prove a useful asset to a travelling expedition remaining for short periods at any one site wishing to collect fauna in the search for new species. In this study the chemical unit extracted thirty-six

spp. of Acari and twenty-three spp. of Collembola from rain forest soil. Further research into the use of aromatic chemicals may provide a range of repellents more suitable for particular faunal groups that will make the chemical extraction unit a useful tool for soil zoologists.

ve) The chemical unit would benefit from the inclusion of a sealing ring fitted to the lid in order to reduce the escape of chemical vapours.

vi) A version of a corer described by Fletcher (1977) modified by the author has been built to meet the requirements of sampling in remote regions. This proved to be sturdy, yet light and incorporated a device to prevent sample compression.

vii) A survey of previous studies undertaken by other workers in the tropics is given.

viii) In order to compare the population of micro-arthropods in the rain forest and a mandiocca field in 1978 it was only possible to use a chemical extraction technique.

ix) A full description of the rain forest and mandiocca sampling sites is given.

x) Using the chemical extraction unit there would appear to be no significant differences in the populations of soil fauna from tropical rain forest and a mandiocca field. The reasons for this not being the case are given. It seems likely that the efficiency of the chemical extraction unit using turpentine as a repellent improved when sampling the soil fauna from a mandiocca field. These samples were dryer and had little litter.

xi) The dominant fauna in rain forest and the mandiocca fields soil to a depth of 5cm from the surface were Acari in particular Cryptostigmatid mites that favour habitats rich in organic matter.

The second largest group was the Collembola.

xii) Most of the faunal groups collected from a mandiocca field were poorly represented in terms of both the number of individuals present and the range of species collected. This is symptomatic of a soil having a poor litter and humus layer, and hence poor organic matter content. In addition as it is subjected to greater insolation resulting in greater temperature extremes this may be an accessory factor (Lasebikan 1975).

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Appendix I. Actual number of specimens collected at each site.

Site: 2. Rain Forest. Chemical Extraction Unit. 1978.

Sample No.	2	3	4	6	8	9	25	26	27	28	29	30	31	32	33	34
Date	24/7	25/7	27/7	28/7	30/7	2/8	3/8	25/8	26/8	28/8	29/8	31/8	1/9	3/9	4/9	6/9
Animal Group																
Arthropoda																
Arachnida																
Pseudoscorpiones											1				1	
Araneae							1						1			
Acari																
Prostigmata					1		1			2						
Gamasina										1						1
Rhodacaridae										1				1		
Uropodina					1											
Astigmata	1									2	1		1		1	
Cryptostigmata	3	2	3	2				2	6	7	1	1	6	1	1	1
Collembola																
Onychiuridae			1		1						1					
Poduridae	1			1	1	3	2		1	3				1	1	
Isotomidae			3		1		1	2	1				1	2	2	
Entomobryidae	5	1		2	2		12	2		2		1			2	1
Sminthuridae	3			1			2				1		2	1		
Other Insects																
Diplura																
Thysanura																
Diptera							1	1		2	2	3	2	5		
Coleoptera			1	1	1	2	4	2		4	1	4	4	1		
Lepidoptera									4							
Thysanoptera																
Hemiptera		1			1		5					1	1			
Psocoptera																
Hymenoptera	4	9		1	2	1	3	5	1	3	1	3	1			
Orthoptera																
Isoptera	1				2				3	3		1			1	
Myriapoda																
Chilopoda																
Diplopoda						1		1		2			1			
Pauropoda								1								
Symphyla				1												
Platyhelminthes																
Nematoda			1													
Enchytraeidae			3	2		1	1		1	5	1	2	1		1	
Lumbricidae										4					1	
Isopoda							2									
Gastropoda																

Site: 2. Rain Forest. Tullgren Extraction. I98I.

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Date	31/7	31/7	31/7	31/7	6/8	6/8	6/8	6/8	13/8	13/8	13/8	13/8	19/8	19/8	19/8	19/8
Animal Group																
Arthropoda																
Arachnida																
Pseudoscorpiones		2		2	1				1		2	2		3	1	
Araneae		6		3	4		3	2			3	2	1	7		2
Acari																
Prostigmata	15	22	33	34	20	18	41	12	30	10	44	35	7	45	51	13
Gamasina	16	13	23	25	11	17		8	18	12	25	52	20	14	12	34
Rhodacaridae	5	25	59	22	49	20	5	48	82	21	44	12	2	55	61	54
Uropodina	3	5	8	11	4	5	2	6	4	1	10	14	4	6	15	
Astigmata	23	5	7	11	8	4	12		12		20	11	2	13	15	
Cryptostigmata	900	154	180	389	127	243	300	161	177	99	419	334	113	195	191	169
Collembola																
Onychiuridae	2	4	8	4	3	5		1	8		7	11	2	5	2	
Poduridae	3		14	11	2	10	6		6		10	12		11	13	
Isotomidae	6	12	22	15	10	14	15	3	21	1	28	13	26	9	7	37
Entomobryidae	3	5	9	9	2	7	2	5	4	1	22	3	8	17	2	
Sminthuridae	3	3	4			5	3		4	3		8	5	1	6	2
Other Insects																
Diplura	4			2		2				1	1	4	1		3	
Thysanura																
Diptera		2		2		2	3	4			6		4			7
Coleoptera	5		13	8	11		16	12	2		10	6		14	20	6
Lepidoptera																
Thysanoptera	4			1				1	2		2	3			5	
Hemiptera	1	6	12	8	10	7	16	5	11		19			21	13	11
Psocoptera																
Hymenoptera	3	7	11		21	7	19		16	13	23		9	12	20	17
Orthoptera							3									
Isoptera		7		4			4		3	1	4				6	
Myriapoda																
Chilopoda	1			3												
Diplopoda		1		1		1		3	1			2				1
Pauropoda	2	2		6			7	4					1		5	
Symphyla		2		2	1		2	2	2	3		1	2			
Platyhelminthes																
Nematoda			5													
Enchytraeidae			1													
Lumbricidae		1	1	2			1		4		3			2		
Isopoda					4			2			1	6			2	
Gastropoda																

Site: I. Mandiocca Field. Chemical Extraction Unit. 1978.

Sample No.	13	14	15	16	17	18	19	20	21	22	23	24				
Date	5/8	6/8	8/8	9/8	11/8	12/8	14/8	15/8	18/8	19/8	22/8	23/8				
Animal Group																
Arthropoda																
Arachnida																
Pseudoscorpiones																
Araneae								1								
Acari																
Prostigmata							1									
Gamasina				1												
Rhodacaridae																
Uropodina																
Astigmata																
Cryptostigmata		1		7	1			3	1			9				
Collembola																
Onychiuridae	3								2	2	1					
Poduridae	1			1		1	1	7								
Isotomidae	3	1		1					1			1				
Entomobryidae	1					1			1							
Sminthuridae	2			2												
Other Insects																
Diplura																
Thysanura	1										1					
Diptera				1			2	1	1	1						
Coleoptera					4	3	6	4	1	1	3	3				
Lepidoptera																
Thysanoptera																
Hemiptera		2	1				3		2	2	3					
Psocoptera																
Hymenoptera	2						1		1		9	1				
Orthoptera	1	1														
Isoptera																
Myriapoda																
Chilopoda				1												
Diplopoda		1						1								
Pauropoda		2						1								
Symphyla		1														
Platyhelminthes																
Nematoda																
Enchytraeidae																
Lumbricidae		1				1	3		3	2		2				
Isopoda							1									
Gastropoda					1				1							

Site: 3. Recently Burnt and Cleared Rain Forest. 1978. Chemical Extraction Unit.

Sample No.	37	38	39													
Date	10/9	11/9	13/9													
Animal Group																
Arthropoda																
Arachnida																
Pseudoscorpiones			1													
Araneae																
Acari																
Prostigmata																
Gamasina																
Rhodacaridae	1		1													
Uropodina																
Astigmata																
Cryptostigmata	1															
Collembola																
Onychiuridae	1															
Poduridae																
Isotomidae																
Entomobryidae																
Sminthuridae																
Other Insects																
Diplura																
Thysanura		2														
Diptera	1	1	3													
Coleoptera	1	1	4													
Lepidoptera																
Thysanoptera																
Hemiptera																
Psocoptera																
Hymenoptera			2													
Orthoptera																
Isoptera																
Myriapoda																
Chilopoda																
Diplopoda																
Pauropoda																
Symphyla	1															
Platyhelminthes																
Nematoda	2															
Enchytraeidae																
Lumbricidae																
Isopoda																
Gastropoda																

Appendix 2

Specimens of the following taxonomic groups have been clearly identified from sites I and 2. These are preserved at the British Museum (Natural History), South Kensington, London.

Class Arachnida

Acari

Order Astigmata
Order Cryptostigmata
  Family Belbidae
    Belba sp.
  Family Carabodidae
    Carabodes sp.
  Family Galumnidae
    Galumna sp.
    Zetes sp.
  Family Liodidae
  Family Oppiidae
    Oppia sp.
  Family Oribatidae
    Oribatella sp.
    Oribatula sp.
    Oribella sp.
  Family Scheloribatidae
    Scheloribates sp.
Order Mesostigmata
  Family Rhodacaridae
  Family Uropodidae
    Uropoda sp.
Order Prostigmata
  Family Bdellidae
    Eupalus sp.
  Family Cheyletidae
  Family Eupodidae
    Eupodes sp.
    Linipodes sp.
  Family Rhagidiidae
    Rhagidia sp.
  Family Scutacaridae
  Family Trombidiidae
    Microtrombidium sp.
    Trombicula sp.

Other Arachnida

Order Araneae
Order Pseudoscorpiones

Class Insecta

Order Collembola
Family Entomobryidae
Entomobrya sp.
Lepidocyrtus sp.
Family Isotomidae
Isotoma sp.
Isotomina sp.
Isotomodes sp.
Isotomurus sp.
Family Onychiuridae
Onychiurus sp.
Family Poduridae
Family Sminthuridae
Sminthurinus sp.
Order Coleoptera
Family Carabidae
Family Curculionidae
Family Elateridae
Family Scarabaeidae
Family Staphylinidae
Order Isoptera
Family Termitidae

Other Insecta

Order Diplura
Order Diptera
Order Hemiptera
Order Hymenoptera
Order Lepidoptera
Order Orthoptera
Order Thysanoptera
Order Thysanura

Myriapoda

Class Chilopoda

Order Geophilomorpha
Family Geophilidae
Order Scolopendromorpha
Family Scolopendridae

Class Diplopoda

Order Oniscomorpha
Family Oniscomorphidae
Order Polydesmida
Family Polydesmidae
Oxidus sp.

Class Pauropoda

New species collected.

Class Symphyla

Order Scutigerellida
Family Scutigerellidae
Scutigerella sp.

Class Crustacea

Order Isopoda
Family Oniscoidea

Other Animal Groups

Phylum Annelida
Class Oligochaeta

Order Plesiopora prosothecata
Family Enchytraeidae
Order Opisthopora
Family Lumbricidae

Phylum Nematoda
Phylum Mollusca
Class Gastropoda